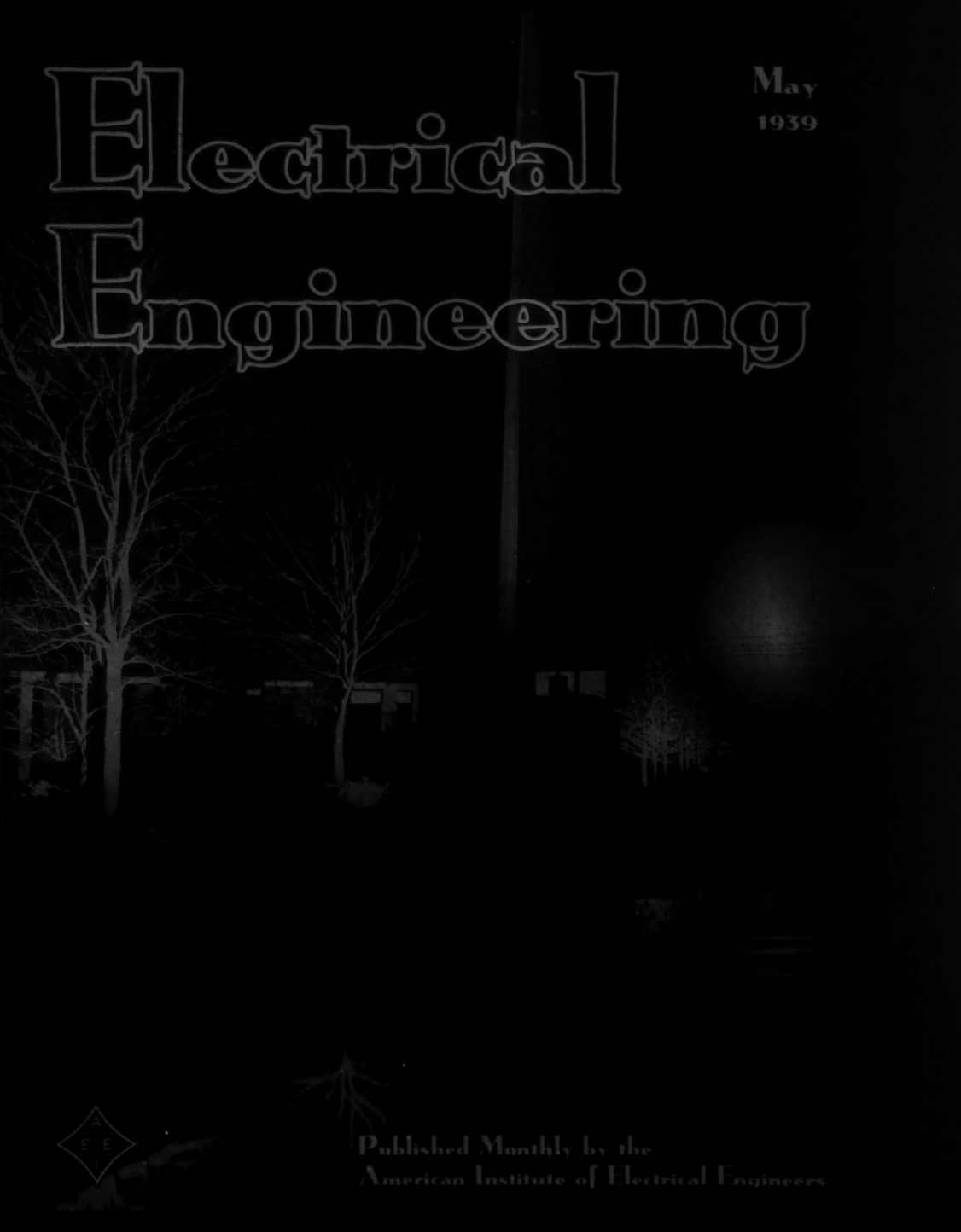
Electrical Engineering

May
1939



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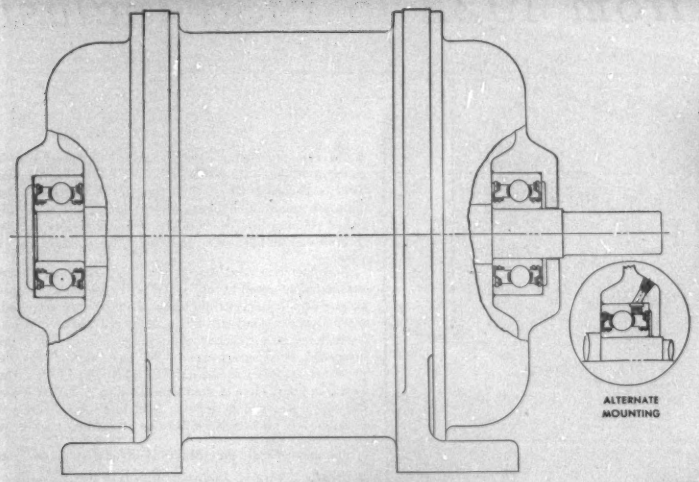
MODERNIZE THE BEARINGS IN

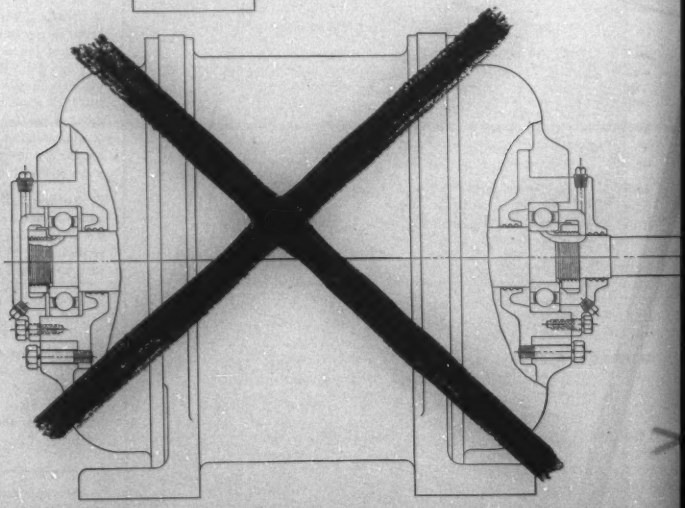


THE IMPROVED

A Part Section of an Improved Motor Mounting with Ultra-Modern "CARTRIDGE" BALL BEARINGS.

THE PRESENT

A Part Section of a Typical Present-Day Motor with Unshielded Ball Bearings in the Conventional Cartridge Type Mounting.



See opposite page for machining operations and parts eliminated from this motor.

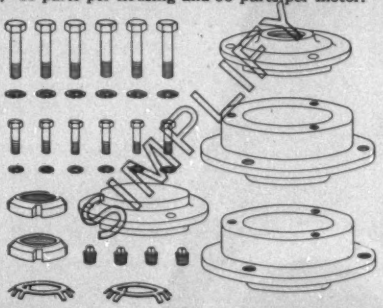
NORMA-HOFFMANN BEARINGS CORPORATION, STAMFORD, CONN., U. S. A.

USE "CARTRIDGE" BALL

YOUR MOTORS!

36 (OR MORE) PARTS ELIMINATED

Below are shown the extra parts required in the conventional cartridge type mounting. THESE ARE ALL ELIMINATED BY USING THE "CARTRIDGE" BALL BEARING,—18 parts per housing and 36 parts per motor.



30 (OR MORE) MACHINING OPERATIONS SAVED

Mounting the "CARTRIDGE" BALL BEARING in the motor housing requires only (1) Boring motor end housing for bearing, (2) Facing housing bore for bearing abutment—4 machining operations per motor.

The conventional cartridge mounting employing the unshielded ball bearing requires 30 additional machining operations per motor.

MACHINING OPERATIONS ELIMINATED

1. Drilling Motor Housing for cap screws.
2. Machining Outer Diameter of Cartridge.
3. Facing Cartridge Flange.
4. Boring Cartridge for Bearing.
5. Facing Cartridge for Cover Plate.
6. Facing Cartridge Bore for Bearing Abutment.
7. Boring Cartridge for Shaft Clearance.
8. Drilling and Tapping Cartridge for Cap Screws.
9. Machining Flange of Cover Plate.
10. Facing Cover Plate.
11. Boring Cover Plate for Shaft Clearance.
12. Drilling Cap Screw Holes.
13. Drilling and Tapping for Grease Fittings and Drain Plugs.
14. Threading Shaft for Lock Nut.
15. Cutting Keyway on Shaft for Lock Washer.

SAMPLE COPY

Developed expressly to improve electric motor design and performance, the "ultra-modern" "CARTRIDGE" BALL BEARING offers the following advantages:

SIMPLIFIED DESIGN: As indicated above, eliminates 36 or more parts,—each an inventory burden and potential trouble-maker. Shortens overall length of mounting and reduces overhang of shaft.

ECONOMICAL MOUNTING: Cuts out the many costly machining operations enumerated above. Assures better bearing alignment because of fewer possible variables.

EASIER AND FASTER ASSEMBLY AND DISASSEMBLY: The "CARTRIDGE" BALL BEARING is handled as an integrally sealed, single unit unencumbered by numerous complementary parts.

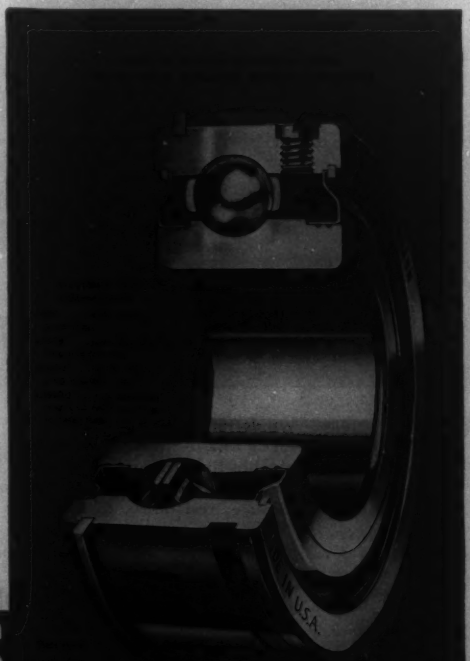
DIRT HAZARD ELIMINATED: Tightly-fitted seals prevent ingress of foreign matter during assembly, in service and when removing armature. The "CARTRIDGE" BALL BEARING comes pre-packed with clean, "stability-tested," uncontaminated grease.

SLIPPAGE, PEENING AND COCKING PREVENTED due to wider race contact area on shaft and in housing. No locking means required and elimination of threading permits use of stronger shafts.

LONGER LIFE AND LOWER MAINTENANCE, resulting from large, lasting grease supply kept in close proximity to rotating surfaces by highly efficient, wearless metal seals. No "dead" grease space and no leakage irrespective of position of motor.

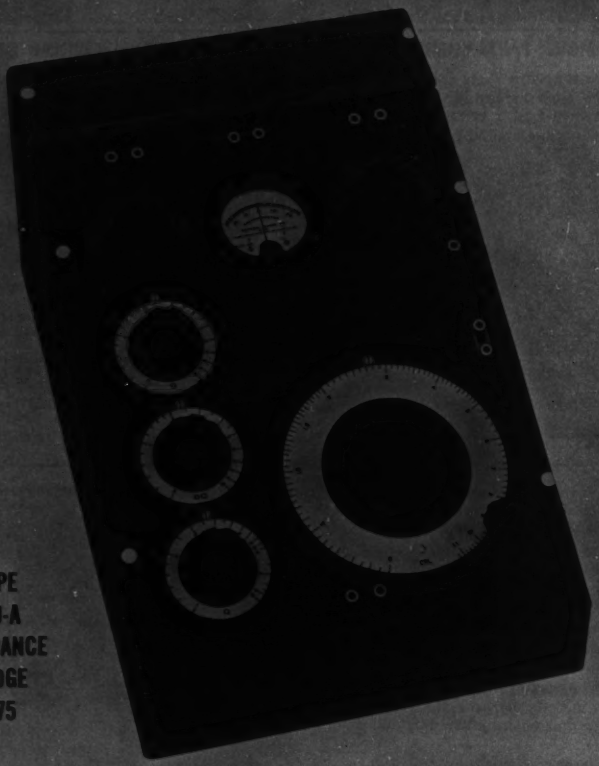
REGREASING AND INSPECTION FACILITATED, refilling plug and removable seals being provided for such purposes.

Let our engineers work with yours. Write for the Catalog.



BEARINGS

FOR MAKING RAPID MEASUREMENTS



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● This bridge—completely self-contained with built-in 1,000-cycle and d-c power supplies—is proving very valuable in hundreds of laboratories and factories for routine measurements of inductance, capacitance, resistance, dissipation factor and energy factor. Its very wide ranges... its portability...its direct-reading feature and its simplicity of operation contribute to the continued popularity of this instrument as one of General Radio Companys most widely used bridges.

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MANUFACTURERS of PRECISION ELECTRICAL LABORATORY APPARATUS

Electrical Engineering

Registered U. S. Patent Office

for May 1939—

The Cover: Trees on Constitution Mall at the New York World's Fair, just opened, are illuminated by 250-watt capillary mercury lamps, one unit underneath each tree. Leaves on the trees will fluoresce under the influence of the ultraviolet radiation from these lamps

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¶ Statements and opinions given in articles and papers appearing in "Electrical Engineering" are the expressions of contributors, for which the Institute assumes no responsibility.

¶ Correspondence is invited on all controversial matters.

High Lights

Electrochemical Industries. Statistics show that in 1936, electrochemical, electrometallurgical, and allied industries consumed some 12.5 billion kilowatt-hours of electric energy, equivalent to more than ten per cent of the total energy produced for public use during that year; with the continuing expansion of these industries and the development of new processes, this rate of power consumption is increasing (*pages 208–16*).

Enterprise and Social Progress. Aside from primitive systems, only two forms or principles of organization of human energy can be defined clearly—*enterprise* and *authority*, says a leading economist who expresses the belief that "we are now reaching a crucial stage in the process of reversion to the principle of authority, and that we shall very soon see a reassertion of social energies, and invasion of authority or government by society" (*pages 193–8*).

Compressed-Gas Insulation. Some use has been made of gases under pressure for insulating media where their properties are desirable. An investigation now has been made to obtain data for pressures as high as 600 pounds per square inch and direct potentials as high as 450 kv, which shows a possible application to cable for d-c transmission because of a definite polarity effect in concentric conductors (*Transactions pages 193–206*).

Summer Convention. June 27 has been designated AIEE day at the Golden Gate Exposition, San Francisco, Calif. To afford all those attending the AIEE combined summer and Pacific Coast convention an opportunity to visit the exposition on that day, no convention events have been scheduled for the afternoon or evening. Those planning to attend the convention are urged to make hotel reservations at once (*pages 217–19*).

Governmental Research. Scientific contributions of governmental research agencies are of high order and of distinct benefit to the public, says a leading educator who continues: "There is need for more scientific research by government to control national defense, to create new opportunities for employment, to improve the products of the farm and shop, and to raise living standards" (*pages 205–07*).

Locomotive Performance. Road tests of the new 3,600-horsepower locomotives of the New York, New Haven and Hartford Railroad illustrate the use of the reserve horsepower and overload capacity of electric locomotives to maintain fast schedules; a maximum of 7,600 horsepower may be obtained on alternating current and 5,500 on direct current (*Transactions pages 212–18*).

Crossbar Switching. A recently developed switching system for dial telephone central offices, known as the crossbar system, employs simple forms of relays and relay-type structures for all switching operations. The system of control is such that two or more attempts can be made to establish a call over alternate switches and trunks when the normally used parts are all busy (*Transactions pages 179–92*).

Capacitors. Power factor may be corrected by capacitors applied to either primary or secondary circuits, but the former is less expensive while the latter offers additional benefits. Results of an economic study indicate that secondary capacitors generally may be justified on secondary networks but have limited application on primary radial distribution systems (*Transactions pages 228–42*).

To 1939 Graduates. Engineering students in the current graduating classes may find in this issue two articles of particular interest: one offers some practical suggestions for obtaining employment (*pages 202–05*); the other discusses some of the social and economic phases of the situation facing the young engineer in this era of change (*pages 199–201*).

Magnetically Controlled Tube. Advantages claimed for a gas-filled tube using electromagnetic instead of electrostatic control for initiation of the discharge include insulation of the control circuit from the tube, operation on extremely low voltages, and lack of reaction of the tube on the impedance of the control circuit (*Transactions pages 224–8*).

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Two Indexes for the Price of One. Those ordering copies of the new AIEE 17-year index, covering papers and discussions published in the TRANSACTIONS during the years 1922–38, inclusive, will receive without additional charge a copy of the last preceding index volume covering the years 1911–21 (*page 221*; *advertising page 1*).

American Engineering Council. Among items appearing in the current AEC "News Letter" are: an announcement of three committees composed of scientists and engineers to assist the President's Committee on Civil Service Improvement; and a discussion of federal relation to research (*pages 223–4*).

Bus Protection. A comprehensive survey of modern practices in bus protection, which presents data from 34 companies, indicates general acceptance of the idea of such protection, and that adequate protection may be obtained by any one of three major methods (*Transactions pages 206–12*).

Calender Drives. An adjustable-voltage system of motor drives is used in continuous processing of automobile tire fabrics, in which rubber may be either applied to the surface or worked into the fabric at production speeds as high as 35 yards per minute (*Transactions pages 218–23*).

Coming Soon. Among special articles and technical papers undergoing preparation for early publication are: an article reviewing some recent advances in electrical measuring instruments, by E. S. Lee (F'30); an article on Elihu Thomson as an electrical engineer, by D. C. Jackson (F'12); an article on highway lighting, by L. A. S. Wood (M'24); an article reviewing recent advances in electric railway signaling, by S. E. Gillespie; a paper describing relay protection for the power-supply system of the electrified division of the Pennsylvania Railroad, by E. L. Harder (A'30); papers on glass, asbestos and glass, and mica insulation, by F. W. Atkinson (M' 37), K. N. Mathes (A'36) and H. J. Stewart (A'38), and R. H. Spry (A'32), respectively; a paper discussing proposed American Standards Association transformer standards by R. T. Henry (F'33); a paper on considerations in applying ratio differential relays for bus protection by R. M. Smith (A'35), W. K. Sonnemann (A'38), and G. B. Dodds (A'29); a paper describing a rectifier for charging batteries on railroad passenger cars by C. A. Kotterman; a paper on methods of voltage control for mercury-arc rectifiers by G. R. McDonald (A'21); a paper on inductive co-ordination of telephone circuits with series highway lighting circuits for sodium-vapor lamps by H. E. Kent (M'31) and P. W. Blye (M'29); and a paper reporting a survey of the lightning performance of 110- to 165-kv transmission lines by the lightning and insulator subcommittee of the AIEE committee on power transmission and distribution.

Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London).

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Enterprise and Social Progress

By VIRGIL JORDAN

The test of any form of social organization is the opportunities it creates for the release and development of human energies, declares this economist. On that basis he contrasts the principle of "enterprise," as it has operated in the United States for 150 years, with the older principle of "authority," and predicts the outcome of the struggle between them.

I PROPOSE to discuss informally, and mainly for the purpose of provoking thought, certain rather abstract ideas about the evaluation of various different principles of social organization. I do so because I think that though these ideas are important for understanding and action in connection with the economic and political problems that we face both in this country and in the world as a whole today, they are as yet largely unexplored. There has been little objective, impartial, and detached analysis in the United States of certain of the psychological or intangible elements that have underlaid the development, operation, and results of our own business system. An endless amount of literature has appeared in this country expounding in great detail the way various other economic systems—socialistic, communistic, Fascist, totalitarian, Nazi; theoretical or actually in operation in other countries—have developed, and how they work and what their results have been. Yet, in the United States where we have lived and worked in a type of economic organization in many respects unique in the world's history, we have given very little conscious attention to its real nature, the principles upon which it has developed, and the way it has operated.

At this stage nothing I can say about this whole field of problems can be considered in any way final, or even can carry much conviction, but I hope that these ideas, vague and disconnected as they may seem, may stimulate others to push thought along these lines. If any problem is important for all of us, whatever our special interests may be, it is that of evaluating the effectiveness of various types of social organization. We are confronted immediately and inescapably with the issue of making a choice among them, in the United States as in many other countries, and those choices are being dictated by the course of events, without any full understanding of the things involved in them.

I want to put out of the way at the outset two preliminary questions to which I frankly confess I have no answer, though they are fundamental. The first is whether or not people do actually choose deliberately the principle of social organization upon which they build their society or their lives. Is that choice in any sense conscious on anybody's part, or is it the product of the people's character and conditions of life? This is one of the unsolved problems of human thought, like the old one about the chicken and the egg, but there are very definite opinions about it. Perhaps the most prevalent in our time has been the Marxian point of view, so-called because it is associated with Marx's general belief that the character of the political and economic institutions in a society is determined rigidly by fundamental economic conditions. The theory of economic determinism, or the materialistic conception of human history, as expounded by Marx, is the view that people do not voluntarily determine the form of their society and the principles of their social and political organization, but that these arise out of the material conditions of their life.

My own view is noncommittal. I have no confidence in any definite answer to that question, but I do believe that it is not appropriate for human beings in any place or at any time to be fatalistic about the matter—to feel that their social destiny, the form of their institutions, is quite beyond their control, and really rests in their stomachs rather than in their brains. I prefer to think that even if it is quite futile they ought to try to do something about it anyway. So I believe that the qualities of character and the capacities of a people are the dominant or determining factors in the development of their political and social institutions, and that these qualities and capacities can certainly be influenced and developed. If this were not true our whole educational concept would be quite useless and should be abandoned. It should be noted that the socialist and communist view is in fact just the opposite, attaching supreme importance to the educational process.

The second question which I must leave up in the air is the very ancient one as to what is social progress, after all? How do we define social progress? I suppose that has been the essential subject of all philosophical speculation since the beginning of time. I recognize that almost any conception of social progress can be considered valid, for certain purposes, but I cannot consider them all, and as an economist I must confine myself to those things that fall within the proper view of the economist and his science. To him social progress must be measured by the effectiveness of a group in increasing its production of wealth—of things that it finds useful. The human or moral qualities associated with the production of wealth, all the problems of individual character involved in productive effort, are matters that do not fall within the field of economic science, and therefore must be left out of my

Address presented at the AIEE winter convention, New York, N. Y., January 25, 1939.

VIRGIL JORDAN is president of the National Industrial Conference Board, Inc., New York, N. Y. An economist, he has also been writer, teacher, and editor. A biographical sketch of Doctor Jordan appeared in the December 1938 issue, page 508.

consideration. This is unfortunate because they are perhaps more important for a sound and constructive evaluation of economic organizations and systems than any purely engineering considerations.

Whatever the answers to these preliminary questions, which I have mentioned merely to put aside, we all recognize that the essential problem of society can be stated this way—and it is almost an engineering statement: *to develop, release, and utilize sufficient human energy to combine enough materials and physical energy to support and defend that society.*

The utilization of human energies, natural materials, and physical forces by a group to support, defend, and expand itself is a circular or spiral process. The more that human energies are released in combining materials and physical forces to increase the support of the society, the more the available human energy will be increased. There is no end to the process, but the essential elements in it, on which I want to concentrate attention, are the human energies themselves and their maximum development and release. This is to me the most important objective or test of any principle of social organization.

The release of these energies can express itself in many ways. It must express itself first in the increase of the population, which is the arithmetical way of increasing human energies or releasing them. You must have more people if you are going to have more human energy. You must prolong human life. You must enable individuals to express or release their energies over a longer period of time, and you must open every channel of expression of human energy and of human control over materials and natural forces. In other words, the conception of the release of human energies is the opposite of the primitive belief, which still persists among a great many people, that the objective of life and of social and political organization should be the greatest possible passive consumption of materials and physical forces in the form of commodities which provide human satisfaction, with the least possible creative activity on the part of the individual himself. The latter conception of the goal of social organization is becoming more and more prevalent. It contemplates a sort of return to the embryo state—to pure passive acceptance or absorption of energy and materials from the outside world, made possible by a vast industrial organization and an all-provident state which together serve as a kind of uterus for the individual citizen. In contrast the conception which I am trying to emphasize as the goal of any principle of social organization, is an active or creative one—the greatest possible release of individual human energy rather than the greatest possible absorption of satisfactions by the individual member of society.

The ways in which materials and physical forces may be combined and utilized for human purposes are governed by laws ascertained by individual human intelligence. Since nature does not recognize persons, these laws are the same for all individuals. Their application is not affected by the number or the character of the individuals who apply them. They have nothing to do with their effects on society and its problems. They would exist just the same even if there were no human beings to use them. But the ways in which human energies can be most effectively developed, released, and utilized to apply these laws are an entirely different matter. There we enter a field outside the scope of the engineering sciences. We enter an unknown territory, a dark forest, about which we have scarcely begun to understand anything scientifically.

We talk in broad terms of human energies, without really believing that we know anything about their effective release. We use the phrase merely to indicate a desire to do something of that sort rather than a belief in our ability to do it. We amuse ourselves by elaborately manipulating a lot of little statistics to measure a vague thing we call public opinion. We have "institutes of public opinion" which attempt to measure statistically the movements of this mysterious entity that is in the background of all our problems and thoughts. In England they have developed that type of activity into a new science or business called "mass observation," which is the same thing, a collection of statistical computations about what people say to somebody about something. That is the nearest approach that has been made after all these centuries to a scientific determination of the ways in which human energies move, the way in which they are released or confined, how they flow in this or that channel. Our ignorance offers opportunity for a vast amount of charlatanism in manipulating public opinion, and in experimenting in "public relations" for all kinds of trifling purposes. The great problem of determining the basic principles upon which immense amounts of human energy may be moved to this or that constructive or destructive purpose, the basis of such movement, the laws that govern it, is all unknown ground. Yet that is the essential problem of all the social sciences as distinguished from the engineering sciences.

Economics, political science, sociology are based on the movement of human energy, which we must understand and measure if we are ever to guide it effectively for economic, political, or social development. The basic question that all the social sciences have to answer is: What principles of economic and political organization tend to develop and release human group energies most effectively? There is no experimental method that can be applied to this problem. All the light that we have on it is shed by the study of history and human experience. We have to look at what human energies have done in the past, how they have moved, what seems to have influenced their movements in this or that direction, and try to deduce from the historical records some conception of underlying principles or laws.

We have about 5,000 years of recorded human history to go on, and there has been a lot of poring over that record for this purpose. After all that study, I think most social scientists, whatever their school of thought in relation to current problems, will agree that, aside from the primitive systems of which we know very little, only two forms or principles of organization of human energy can be defined clearly. They have been given many names, but I prefer to give them those which I shall use in this discussion—the principle of *enterprise* and the principle of

authority. I shall try to define and clarify these two principles of human organization.

There are very few examples of the principle of enterprise. It is questionable whether there were any before the last 150 years on this continent. Some historians say that the Greek Republic was a fair example of the application of the enterprise principle in the release of human energy, but it is a doubtful case and its examination does not teach one much. The only way we can get a clear conception of what is meant by enterprise as a principle of human organization is by contrasting it with its opposite, authority, which has been the principle most continuously applied during all the human record of which we have any real knowledge.

The contrast between these two principles is not the contrast between capitalism and socialism. Such a contrast is wholly misleading. All societies, even the most primitive of which we have any knowledge, are and must be essentially capitalistic in their economic operation. All economic progress, all elevation in the standard of living, is attained only by the use of some kind of tools, something more than man-power. Every society has to have tools if it is to survive, even if the tools are nothing more than swords, clubs, or other weapons of defense. The real questions are how the capital of a society is created, on what basis or principle it is utilized, and how effectively.

Likewise the distinction that is perhaps even more common today, between democracy and any other principle of government, is largely irrelevant. The question is not what form government or the state has, or by whom authority is exercised, but how extensively it is expressed in the social organization in comparison with the social energies of the population themselves. Relatively, all forms of government are the same, because they are essentially a restriction of human or social energies. In one way or another they are inevitably in competition with the energies of the society and the social resources.

To understand the real distinction between enterprise and authority as principles of social organization for releasing human energies, we must remind ourselves that the individual human being is an energy center, a nucleus of potential energy. From a metaphysical point of view, perhaps the individual is the only real center of energy; but that is a matter of speculation. At any rate he is a center of a type of energy that cannot be measured or comprised strictly within any of the known physical laws of conservation of energy. The human individual as an energy center seems to be one instance in which the whole can be greater than the sum of the parts, and the output greater than the input. But whatever the laws regulating that type of energy may be, we have to recognize that this individual human energy, which is the basis of all society, is in various ways heightened or diminished in its level at any time by contact with other human beings in groups. The energy level of the individual is a function of the energy level of the group and may be affected by the principle of social organization, or the influence of institutions, government policies, and "leadership" personalities, in frustrating, dissipating, or increasing the social energy.

The essential distinction between enterprise and authority in relation to the release of human energy lies in the fact that under the authority principle the social energy—that is, the energies of all the human individuals composing the group—is directed through specific channels established by some outside authority, such as the state, the church, or some representative of personal power. Thus the energies of all or most of the individuals composing the society are used to build up power for the controlling authority instead of being exercised creatively on the environment in mastering materials or physical forces or in developing the energy of society as a whole.

The authoritarian type of human organization is the oldest and most persistent, perhaps because the symbol of authority—the father, or king, or church, or government—has some magnetic power to maintain channels or lines of force by which human energies of vast masses of people may be controlled. Perhaps the reason for its potency which most frequently meets the eye in the human record is that for most of human history muscle power was the principal physical energy utilized in production, or in any kind of action by the society. The most effective way of utilizing it and combining it with materials was by regimenting masses of human beings to apply muscle power rhythmically and continuously. Hence the acquisition of slaves or wealth by conquest of other peoples, or the production of wealth through slave labor, characterized the whole economic process of society for practically 5,000 years of human history. Its basis was political ownership and control not only of human muscle energy, but also of the capital, or tools, materials, and weapons of production or conquest, because the surplus available to such a society for further production was so small and so ineffective in individual hands that it had to be aggregated and concentrated, in order to be of any use at all.

The use of man-muscle power through regimentation of its human agents in masses for conquest or for productive purposes is the basis of the authoritarian form of human organization. It is the essential principle of what we call feudalism—the oldest method of utilizing human energies in the world—the political control or ownership of property and labor. Property and labor have always been inseparable in the history of the authoritarian principle in human society. You cannot own or control all property without controlling or owning human labor, and even the human being who labors.

The development of science in the modern age made available other physical energy than muscle energy. This is its essential and most important accomplishment. It heightened the potential productive power of the individual human being, making it much greater, even on a very low level, than the productive power of the human mass utilizing muscle power. This vast release of social energy, made possible through the discovery of other kinds of physical energy which could be utilized by human beings, destroyed the intrinsic power of authority as a principle of energy development in human society. That, incidentally, is one reason why through all human history every type of authority is always opposed to the development of scientific investigation and discovery. Its

greatest enemy, the greatest force tending to weaken the principle of authority, has been the power of human knowledge.

Yet even up to the beginning of the 17th century of our history—just a few days ago, so to speak—the restrictive influence of the principle of authority upon human energy was evident all through European society, in the guild system of organization of labor and production, in the diversity of elaborate devices to maintain the *status quo* of productive groups, in the tendency for each group to seek some type of security from king or church or other authority in power. Practically the whole increase of society's wealth was in land and in gold and a trifling quantity of jewels which could be used in trade between countries. That wealth was gained by conquest, mainly, and held by the insignificant few in whom authority was vested by divine right, descent, or on some other basis. Beyond that there was only the barest subsistence for the great mass of human beings. Land, castles, cathedrals, monasteries, immense public works, armies and navies, symbolizing or expressing the power of the authority in force, were the characteristic and most important forms of wealth and production in society. The population of any particular society was increased largely by conquest, because it was worn out very rapidly through its utilization by authority as the main means of wealth production. The population of western Europe was practically stationary up to 300 years ago. It has about trebled since.

The enterprise principle, which is really the creation of modern science, and carries over the essential spirit of modern science into the field of social, economic, and political action, changed the whole panorama of human progress suddenly. Instead of the picture of the chariot, representing the principle of authority, drawn by great masses of human beings along a practically level road, there has been substituted—the only picture I can think of that represents it—a picture of an escalator, in which you have great populations ranged on the various steps, most of them at the bottom, fewer at the top, but the whole mass being raised in its standard of living through the release of the total energies of all the individuals in it, while at the same time the individuals on each of the steps have been walking upstairs through their own particular energy, and so shifting the composition of the group constantly. This has meant an unparalleled release of human energy as the center of power passed from the authority of the state to society as a whole.

The elements that accounted for that release are many, and some of them are well recognized—the use of mechanical power through steam, which was later made infinitely more elastic and flexible by electricity and oil; the whole credit mechanism, which came into existence at just about the same time as the industrial revolution; and the corporate form of enterprise. All these came into existence about the same time, enabling the pooling of individual risks of enterprise, creating many small and diversified risks instead of one large and concentrated one, providing greater flexibility in application of labor capacity and capital.

These are vital factors, but they carried with them others that are equally vital—the principle of private property; the principle of individual contract; the principles of choice of occupation and freedom of physical movement from one place to another; the principle of connecting risk and reward, loss and profit; the principle of stimulating and developing diversity of accomplishment and capacity, instead of creating the greatest possible uniformity throughout society.

All these factors and principles underlie the enterprise concept of human organization, and they all acted and interacted with one another during the so-called industrial revolution to bring about a tremendous release of human energy that overflowed the channels established by state and religious authority, and expressed itself in an unprecedented increase in the population and rise of the living standard of western Europe.

This release took effect much more in America than in Europe, where many of the old channels of flow of human energy have persisted in fossilized form, and have been very difficult to break up. The American Revolution, occurring in a new territory essentially without preexisting institutions to determine the channels of release, created an unprecedented opportunity to test the effectiveness of the enterprise principle. The American Revolution was much more than a release of human energies in the form of productive accomplishment. It was essentially an aggressive invasion and forcing back of authority almost to the point of destruction. It has been called the only real revolution in human history, for the reason that its primary object was to restrict almost to the point of annihilation the power of state authority over human energies.

It is unnecessary at this stage to emphasize again the outstanding and unparalleled nature of American accomplishment under the enterprise principle. I used the escalator simile to interpret this accomplishment, and the United States is the only country to which it can be applied. It gave the population on the steps of the social escalator, for the first time, a somewhat normal distribution—that is, a distribution according to the energies or creative capacities of the individuals.

For all of human history before there had never been anything like such a distribution of the population in economic terms. We have heard in recent years frequent use of the phrase "underprivileged classes," with great emphasis on the fact that in the United States one-third of our population is underfed, ill-clothed, or ill-housed. But a population of which only one-third is underprivileged means a population in which two-thirds is privileged. This is the first time and place in human history that there has ever existed any people among whom two-thirds could be said to have privileges of any kind. The characteristic distribution of human society up to the time of the American Revolution and the application of the enterprise principle in this country was a vast uniform mass of human beings whose status was permanently fixed, contrasted with an insignificant fraction of the total population which could be said to have some sort of privilege or position or opportunity.

Through the application of the enterprise principle in our own economic development, the per-capita income of the whole population has tripled in a single century—a rate of increase in the standard of living that has no precedent in the human record. That increase is not the only important feature of the working out of this tremendous release of human energies under the enterprise principle in the United States. The nature of wealth itself has been altered completely. For the first time, we have created in the United States a conception of wealth entirely different from that held by human society up to 300 years ago. We have a wealth that is a dynamic, fluid thing, the value of which is created solely by its effective capacity to provide useful goods and services, not by any authority. Our wealth today is productive power, not the power of authority. The things that are productive, the energies that are productive, including human energies, all enter into our conception of wealth, as contrasted with gold, land, weapons, castles, cathedrals, public works, or any of the things created for the glorification and strengthening of authority in ages past. The effectiveness of our wealth, its real value, is measured by its capacity to increase the consumptive power and productive energy of the great mass of the people, not the ruling power of the state. If it cannot do that, it ceases to be of value in our eyes. This change in the nature and conception of wealth is perhaps the greatest result of this experiment with human organization under the enterprise principle.

Today in the United States we are faced with the question of the future of this experiment. In all the rest of the world we are witnessing a reversion to the feudalistic principle of organization—authority as the basis of control of human energies. The world over, there has been what one might call a counter-revolution, a reassertion of the principle of authority as against the social energies. Here in the United States some feel that we are witnessing the beginning of a re-conquest of America by Europe, in the sense that Europe, the old breeding-ground of authority which never really came under the influence of the enterprise principle, is reasserting its influence over the character of our own social organization.

The effects of that change are not yet clear. We are living among them; we are too deeply immersed in them to be able to see them. The fact of the change, however, and the weakening of the enterprise principle both in the rest of the world and in the United States, are clear enough. We see many evidences and symptoms of it in the declining rate of increase in the population and per-capita productivity of this country. For instance, the per-capita real income produced by private enterprise in the United States is now less than it was 30 years ago, while the proportion of the national income produced or distributed by the state has enormously increased. Government in this country has distributed in money income to the American people in the last four years more than the total net product of all the business enterprise and all the individuals in the United States. The evident decline of certain types of enterprise energies, the gradual expansion of governmental activity in every field, the increasing importance of the state as an energy-absorbing agency in our society, are all indications that the balance between authority and enterprise has been somewhat altered in recent years.

The many intangible factors behind such a change would take long to discuss, and one cannot be quite sure of them. We see some suggestion of what they may be in the declining rate of population growth, evident since the beginning of the current century, and in the rapid urbanization of the population, which has made the individual increasingly dependent for support upon employment by someone else, rather than upon his own enterprise energies.

Another possible evidence of the decline of the enterprise principle is the increased amount of capital in tools and construction needed to support or to employ a single individual. Under our present economy about $10,000 worth of fixed and working capital is required to produce enough to employ—that is, support—one person, as compared with approximately half as much in the first half of the last century. That, too, has meant increased dependence of the individual upon employment, investment, and enterprise by others, rather than upon his own resources. The growth of large-scale enterprise offering employment to large numbers of people has developed in the population as a whole the concept that our industrial mechanism has become a sort of Aladdin's lamp—something that operates automatically by the use of enormous amounts of physical energy, and can provide an abundance of goods and satisfactions without corresponding exertion or release of human energies in the process. Great numbers of the human population feel more and more that they can live passively, and need not participate in production as much as they do; or, to put it quite plainly, that they need not work so much and utilize their own energies so much in order to get a living. Along with all this has undoubtedly gone an increased tendency of the typical representatives of enterprise, our industrial and business concerns, to utilize the state and to depend upon the principle of authority to increase their own power, or maintain or improve their own position in the enterprise game. That tendency has correspondingly operated to weaken the force of the enterprise energy of the individual.

The influence that has done most to break down or weaken the enterprise principle in this country was the World War, which was the most destructive event in human history, by any terms of measurement, and resulted in the greatest dissipation of human energy, of human life, and of capital, that the world has ever seen. Since the war the real energy level, not only of the United States but of the whole world, has undoubtedly been lower than it was before.

Today as we look at the accomplishments of the enterprise organization and the signs of its weakening, what attitude should we take toward the problems that face us in the future?

I think that in our own country, and certainly in most of the principal countries of Europe, the control of human energies and of capital—of the social resources, in short—by authority, by the state, has gone so far that the as-

sumption of ownership, both of property and of the human energies involved in its use, is an inevitable and logical consequence. In most countries there is now such complete control over the use of physical facilities and of human energy in productive activity, that there is no responsibility left for the individual owner, manager, or worker—and responsibility is only another name for the exercise of human energy by the individual.

When that stage has been reached, the actual assumption of ownership and the expropriation of the energies and the property would seem to be inevitable. We would have in essence completely reverted to the feudalistic principle of social organization, in which all property and all human energy were actually owned, as well as controlled, by an authority of some sort—state or church as the case might be. But at that stage, in the light of the whole background of modern science and its effect upon the productivity of human beings, there must be a breakdown of the effectiveness of the principle of authority. It cannot operate in the end under the conditions that have been created by modern science, and one of the principal reasons for that, I think, is that the risks are too great. When all responsibility and authority are concentrated in one agency, the risk of error is magnified almost infinitely. Under the enterprise principle, which applies human energies in diversified and flexible ways, social risks are minimized. The risk of error in our vast, complex modern social organization becomes catastrophic—too great to be borne by any single agency. The peril of breakdown of this integrated network upon which all of our society must live is so great that no agency can assume that risk. If any agency does so, it is almost certain to make an error which will destroy the whole fabric. I think we are now reaching a crucial stage in the process of reversion to the principle of authority, and that we shall very soon see a reassertion of social energies, an invasion of authority or government by society. I think groups will begin to resume for themselves functions that have been taken over by authority, and to break up large national problems into small pieces which can be managed by the social energies and resources available locally.

In this sense I am hopeful about the outlook, although I think it will be extremely difficult to make the transition to a restoration of social resources from the application of the principle of authority on such an extensive scale that it covers almost every aspect of our lives. To withdraw to a more vigorous application of the enterprise principle is going to involve strains and stresses of very serious character. But I am sure that we are going to survive them, because the development of the enterprise principle in the great American experiment has brought into the field of social action, into the utilization of social energies, a new method of such vast creative power that I doubt whether it will ever again be lost to the race.

A nightly display at the Lagoon of Nations, New York World's Fair, combines light of many colors from 585 submerged twin projectors, water rising 160 feet into the air, and music, gas flames, and pyrotechnics. A keyboard controls the combined effects. Colored lights also encircle the fountain and searchlights illuminate its jets

The Young Engineer Facing Tomorrow

By WILLIAM E. WICKENDEN
MEMBER AIEE

"Young engineers stand the shock of adjustment to the world of work better than college men in general"

TO ANY of our older engineers who may have grown pessimistic over the future, an opportunity to rub elbows with the men yet in college ought to be a reassuring experience. You are facing life in an exciting period when change is the only certainty that can be counted on. All around you are student groups caught, for the moment, in a wave of emotional radicalism, but if you are like the other 2,500 young engineers I have known and worked with these last ten years, you can be depended upon to keep your heads. As engineers you believe in change but distrust propaganda. You realize that the prevailing social scheme is not the product of design, but rather the residue of millions of trial-and-error experiments spread over ten thousand years of civilized history. What worked was retained; what failed was discarded. There is a time-lag in this rule, but it works inexorably. When a Karl Marx or an Adolf Hitler goes into silence and brings forth the blueprint of a new society, you view it with a healthy skepticism. The odds of experience are against it.

As engineers, however, we cannot remain satisfied with progress through trial and error. Our job calls on us to replace guesswork with rational planning, wherever possible. We believe in experimentation, imaginatively conceived, rationally controlled, and rigorously checked. Our interest is roused by two decades of experiment with collectivism in Russia, in Italy, in Germany, and under less coercive guises in the United States. A critical stage in these experiments seems near at hand. The result? The pendulum seems to be starting its long swing back to the ideals of freedom. If that is true, it may mean much to the seniors of 1939.

Some fruits of recent experimentation will doubtless endure. Bankers now accept the SEC instead of fighting it. Insurance men are reconciled to social security measures. The utility interests expect government to develop water power. Industry generally is lining up for collective bargaining. Sober citizens who begrudge the waste of public funds on hastily improvised projects recognize the necessity for long-planned spending on public works as a counterpoise against violent swings of the economic cycle. Collective wealth is increasing faster than private wealth. Permanent gains are being made in the conservation of soil, water, and mineral resources and in public facilities for education, health, and recreation.

Many of you may have more to do with public welfare than with private enterprise, and these new trends may largely shape your careers. A growing proportion of you will probably find careers in government service. This may be good for your profession, by making a more even balance between the individualistic practitioner and the career man and by affording a wider choice between technical and executive types of responsibility. Equally, it should be good for government, helping to even the balance between social visionaries and fact-minded men. If engineers are to take a larger part in government, it is the concern of all of us to make government a better place for engineers to work. We ought to pull together for fair compensation, for a more rational grouping of engineering functions, and for their removal from direct political pressure. This is not a remote issue; it may touch next year's bread and butter for many seniors. Honest engineering calls for clearly defined responsibility, for reasonable freedom of initiative, and for non-political tenure. Do you want your job to depend on getting the initials of the right political boss? Do you want your decisions revised in the interest of the election returns? Do you want to be caught in a mesh of red tape? Can you expect to work well in a confused, overlapping, or isolated organization?

Facing tomorrow, it is time now to stop taking the economic world for granted. It will be well for you to reckon your stake in free institutions and in free enterprise. This principle of enterprise is not something remote or abstruse. It is the inner drive which urges men to get on and not merely to hold on, to depend on their own efforts rather than the paternalism of the state. It spurs the scientist to wrestle with nature, the inventor to strive for a novel product or a new way of doing work, the thrifty man to sacrifice in order to save and to own, the financier to take the risks of a new industry, the engineer to plan, and the executive to organize for increased efficiency. What we call capitalism is the fruit of freedom and enterprise in the world of work. Free enterprise, it is pretty generally agreed, will work well only in an expanding economy. In the past, spreading frontiers, virgin resources, and rising population have supplied the expansive force. Now we have to seek it in raising the general standard of living of a population predominantly urban and industrial.

Free enterprise, when wisely directed, tries to raise

Although this address was delivered to a group of civil-engineering students, it is believed to be of interest to all young engineers; manuscipt made available by Sidney Wilmot, editor-in-chief, American Society of Civil Engineers, for simultaneous publication in *Civil Engineering* and in other society journals.

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living standards by multiplying wealth, while state paternalism almost always ends up in attempting a solution by dividing it. What happens when an attempt is made to distribute social benefits before they are produced has been all too apparent in France. Higher wages, shorter hours, paid vacations, and multiplied insurance schemes, unmatched by effort to raise the efficiency and volume of production, have served only to raise the cost of living, destroy markets, reduce employment, weaken the franc, and threaten the nation with impotence in the face of strongly organized enemies. Every engineer knows that permanent gains in wealth and leisure are the by-products of rising efficiency, and cannot be created by government subsidy; that the way to cure unemployment is to create more jobs through research, thrift, and enterprise, by developing new products, by creating new industries, and by translating technical advances into reduced prices and wider markets. One quarter of all our employment today is said to be in industries which did not exist before 1880.

In our modern industrial society we thrive not merely through what we spend for goods quickly consumed, but through what we spend to put more men to work. On the average, it costs about $7,600 today to equip a worker for his job. In the steel industry, the figure is said to be $11,500 per worker and in the electrical utility industry, $47,000. The flow of new capital into investment has all but stopped, under a public policy of policing industry rather than encouraging it, and there is little prospect of healthy recovery until it is re-established. The accumulated deficit of capital replacement and new investment of the last decade has been estimated at something like 150 billions. This is a vital matter to engineers. We spend the money which prepares jobs for men, directing it through construction and manufacturing channels into wages and purchases of materials, through which it ultimately is transformed into purchasing power for consumption goods. Engineers can thrive only when society thrives by multiplying its economic capacity.

Facing tomorrow, you are facing the risks of decision which mark off the man from the boy. Heretofore, most of those risks have been taken for you by parent, school, or teacher. You will be tempted, in the spirit of the times, to prefer security to adventure. Most of you who do so choose will settle into mediocrity. If you have not had the privilege of going away from home to college, try for a job in some other town. Finish the job of growing up, if possible, out from under the wings of the family and the college which reared you.

The engineer does not shun risks, but he takes them prudently. It will be important to you to choose a field which challenges you, but one in which you can succeed by reasonable application and effort. Success is a habit, and not a lucky break. Education comes through success, in getting a taste of achievement which creates a craving for more. Men are lured to success, not driven. If you succeed it will be because you are spurred by inner drives rather than by outside rewards.

You will begin life in a competitive struggle, but with odds in your favor. President Compton of Massachusetts Institute of Technology, reporting on a study of 54,000 officers of 500 corporations, has stated that the college man is seven times more likely than a non-college man to become such an officer, but that an engineer is thirty times more likely than a non-engineer. The advantage is great, but it is well to judge the odds in the light of changing conditions. Going to college has become a generally accepted social habit, much as going to high school became twenty-five years ago. One young person in seven enters college today. Place beside this fact another, namely, that about one family in seven is above the income level of $2,400 per year, and it is plain that college-going has about caught up with preferred opportunity in our present society.

The odds are with you, but they will not save you from the relentless sifting of the first five years out of college. The shock of passing from college, where everything conspires for your development, to a realm of repetitive work has been likened to shifting a fast-moving car from high to low gear. It is a jolt to find that you are expected to go on with work after you feel that you have exhausted its learning possibilities, to find yourself and most of those about you using so little of what you learned in college, to have a boss who pushes you on output while you have to push him if you wish to learn anything. You will find that where a hundred men will learn under the organized routine of a school, or ten under the inspiration of a voluntary group, only one will keep driving ahead under his own power.

When you discover that you must now fight your own battle for self-development, you will be tempted to work for yourself rather than your employer. You will want to be a brilliant performer and to go places in a hurry, with dreams of a vice-presidency at 30. Then some day you may awaken to the fact that too much zeal of this kind is holding you back, that you are really heading for one of those "lone worker" jobs which are blind alleys in most organizations. At this stage, a good football player is likely to hold an advantage over a brilliant scholar. To get ahead on the main track, you will have to learn to put your organization first and to adjust yourself to the tempo of group activity. You will have to get others to perform and not merely perform yourself. You will have to learn to judge men, fit them to their tasks, train them, iron out their troubles, check their performance, appraise and reward their work, and inspire them with organization spirit.

The first five years after college are usually the most critical of an engineer's career. For one who is held back by lack of knowledge, ten are stalled through inability to surmount routine. The Engineers' Council for Professional Development recognizes this as one of its major problems. Now that it has carried out so successfully the work of accrediting college curricula, its next great task is to aid its component societies in so guiding and stimulating young engineers that the curve of personal development will less frequently flatten off in this period. Within the colleges there is concern everywhere to give engineers a large share in activities which make for self-assurance, team-work, capacity, and imaginative leadership. Many of us have stuck too close to the curricular grindstone.

Educators of all sorts are observing that young engineers

stand the shock of adjustment to the world of work better than college men in general. They have a clearer sense of direction. Fewer of them flounder. They know the worth of discipline. Sustained work is no novel experience, nor does physical effort appall them. Few are troubled with conflicts of personality. They accept economic realities. Employers have long since recognized these qualities, and the depression years have emphasized the engineer's preferred position. To the seniors facing tomorrow these are grounds for self-confidence, but not for overconfidence. The make-or-break test lies just ahead. The critical question is "Can you surmount routine?" Every good college of engineering trains men for careers of decision and action. Their opportunities are boundless, but they set their own limitations of achievement.

Facsimile Broadcasting in California

REGULAR facsimile broadcasts of a morning newspaper to 100 subscribers now are being made by the McClatchy newspapers in Sacramento and Fresno, Calif. The service, which began February 2, 1939, uses standard broadcast frequency bands to transmit signals and synchronizes senders and receivers through the interconnected facilities of the Pacific Gas and Electric Company. While experiments with the equipment have been under way for several years, this is the largest regular service yet attempted and the first use of facsimile network broadcasting.

Written and set in type at the offices of the Sacramento *Bee*, the *Radio Bee* is broadcast from station KFBK there and by wire over station KMJ in Fresno, under a Federal Communications Commission order permitting radio stations 50 facsimile receivers each. An eight-page paper (page size $8^1/_2$ by 11 inches) comes from the receiver in an eight-foot strip. Over 4,000 words in 10-point type can be transmitted in an hour.

The signals which cause a printer mechanism to reproduce printed matter (pictures or text) are produced by a mechanical-photo-electric scanning equipment, the output of which modulates a standard broadcast transmitter. The signal is amplified upon reception to actuate a printer bar magnetically. Paper and carbon paper are held between the printer bar and a helix rotating at 75 rpm, so that the point of intersection of helix and bar moves in a straight line across the paper as the helix rotates. When a signal causes the bar to move, a black dot is printed at the point of intersection. As a line is completed the paper has moved forward $^1/_{125}$ of an inch, and the next line is printed.

Operation is synchronized by means of synchronous motors on an interconnected a-c system. Correlation within a line is achieved by "automatic framing." A signal is sent from the broadcasting station before each line is printed, and if the receiver is not in correct position, the synchronous motor is caused to slip, the operation being repeated until framing is correct. This process, which occupies several minutes, takes place when the time-controlled receivers are first turned on, in the early hours of the morning. Within three hours the paper is completely printed and ready to be torn off the receiver.

Since the mechanisms are simple and may be serviced during the part of the day when they are not in use, low cost is possible. At present the sets are not for public sale and no fees are paid by subscribers. The equipment is that of the C. J. Young system, announced last year by RCA and being demonstrated at the San Francisco Golden Gate Exposition.

Engineering Schools and Engineering Industries*

NO engineer can contemplate the whole field of his profession without the thrill of recognizing the leadership of science—the new knowledge which is remaking the physical world. But most of the achievements of science require the services of the engineer, whose care it is to translate facts into physical form for the use of society.

To teach what the facts of nature are and particularly how to apply them to social purposes is the function of the engineering school. It is obvious that if it taught only the facts without the application, its students would be scientists and not engineers. The art of applying science requires as much study as science itself but is exercised in a different realm, one peopled with men and women rather than facts and principles, concerned with social rather than natural laws, and revealed through the whole group of studies known as the humanities.

Certain qualities of character, as well as of mind, are essential to the successful practice of the engineering profession, because all engineering is ultimately involved in some way with industry. There the factors of labor, capital, and management meet those of science, with results which are changing the physical world. Partly because of his new knowledge, and partly on account of the methods of thought in which he has been trained, the engineer has come to fill in industry a broader place than engineering alone. He has become important in the function of management, occupying a pivotal position, intermediate between capital and labor and competent to understand the problems of both.

For this reason, students and public are best served by those engineering schools which, looking ahead to industrial responsibilities for their graduates, supply more than mere technical training. With these aims, however, the school must keep pace with the industrial changes going on around it. Only when teachers have opportunities to co-ordinate industrial experience with scientific study can an engineering school offer to industry men properly oriented to meet its demands today.

* Abstracted from an address of the same title delivered by Gano Dunn (A'91, F'12) president of the J. G. White Engineering Corporation and of Cooper Union, at the annual luncheon of the Alumni Federation of Columbia University, New York, N. Y., February 13, 1939.

Suggestions on Seeking Employment

By CHARLES F. DALZIEL
ASSOCIATE AIEE

Some practical suggestions that may aid the engineering graduate in becoming situated in industry

WE HAVE all listened to representatives from industry discuss the timely subject of seeking employment. I think that you will agree with me that in general these discussions have been unintentionally or deliberately biased in favor of a specific company, or a particular field of interest. I have listened to varied presentations of the subject, and have had occasion to discuss the subject with many graduating senior students at the University of California during the last seven years. Since I represent neither an employer nor the unemployed, I shall attempt to discuss the general situation of finding employment from an entirely unprejudiced standpoint.

The first point to be mentioned is that industry desires and employs *college graduates*. Doctor Karl T Compton, president of the Massachusetts Institute of Technology, made a study of 54,000 officers of some 500 typical industries (EDUCATION AND BUSINESS LEADERSHIP, *EE, February 1938, p. 77*). The results showed not only that college graduates have a much better chance of advancement in industry than non-graduates, but also that engineering graduates are actually 30 times as likely as graduates of non-engineering courses to achieve positions of responsibility. He found that the college man was 7 times more likely than a non-college man to become an official.

It is apparent that industry seeks the technically trained college graduate, as evidenced both by this study and common knowledge. It is implied that effort expended in getting a technical education is worth while from an educational standpoint, and also the best known investment. The next consideration is to inquire what industry desires to find in the college trained man. The prospective employer is probably looking for:

1. The enthusiasm of youth, tempered with intelligence.
2. A willingness to do hard and dirty work.
3. A healthy body, the best insurance for uninterrupted output.
4. A sense of humor and a likable personality.
5. General knowledge based on a well-rounded education.
6. A trained mind with sufficient knowledge to permit productive work in some field of industry.

Often an enginering graduate is disappointed after an interview in which the prospective employer fails to quiz him on technical points, and asks such questions as: "Who won the World's Series?" or "Who played in the Rose Bowl last year?" Apparently the employer was attempting to determine the applicant's general knowledge. He was satisfied that the man's technical training had been sufficient; after all, he was a technical graduate from a recognized school of learning.

I knew of a girl who applied for a teaching position in one of our large cities. She was being interviewed by members of the board of education. The eldest, some 80 years of age, asked if she liked modern dancing. She replied that she did, fearful of how this might react on the representative of the older generation. He replied, "Will you demonstate a few of the steps of the Big Apple for me?" Quick as a flash she replied, "I will be glad to, if you will be my partner." She was found capable of handling a difficult situation tactfully, and had a sense of humor. She was offered the position.

Methods of Attack

There are almost as many suggested solutions to the problem of finding employment as there are applicants. Any method of attack that works is a correct one. Perhaps the problem can best be discussed by asking and answering questions. Let us proceed along this line.

Question: Should you use "pull" in locating a job?

Answer: Certainly, use all the "pull" you can muster. You may be hired because of it, but it is self-evident that you will have to rise on your own merits if you are going to get along with your fellow workers and be happy in your employment.

Question: If your pull fails to materialize, a common experience, what are the next best avenues of approach?

Answer: Four methods suggest themselves:

First choice: college interviews. When an employer goes to the time, expense, and trouble of contacting colleges and interviewing college men, he is there for one purpose only, that of finding the best man for his job. He wants to hire a man, and he wants to meet and talk with you. He has made it his business to find out if you are the right man for his needs. Do not hesitate because you may not be at the top of your class. Because of your particular experience, interest, or personality, you may be tops with him. Put your best foot forward, strike while the iron is hot, and land the job, if you can.

Second choice: your father's associates. Don't forget that your father is your most reliable friend. Discuss the problem with your parents, and with your father's business associates. Have your father mention your name to his

Based upon a paper presented at the Mu Chapter, Eta Kappa Nu, employment seminar, Berkley, Calif., March 30, 1939.

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friends, and make every attempt to meet them personally. Accept all invitations for interviews, keep all appointments on time, and show a lively interest even though the prospect may not at first appear to be in your particular field of interest. Many a position has failed to materialize because a friend who had agreed to see what he could do was allowed to lose interest. Remember that both your father and his associates are glad and willing to help not only just any deserving young man but especially you.

Third choice: technical employment agencies. The Engineering Societies Employment Service is maintained for the members (including student members) of the national societies of civil, mining, mechanical, and electrical engineers, in co-operation with four other allied organizations. It is a non-profit co-operative enterprise, and publishes a weekly bulletin listing men available and engineering positions open. Offices are maintained in San Francisco, Chicago, and New York City. The cost is a percentage of the first month's, or the first year's salary, payable after you have been employed. Members of the associated societies should try to visit the nearest office and discuss their problems with the experienced men managing this service.

There are also other technical and non-technical employment agencies which may be consulted. They are probably most valuable to persons having practical experience in addition to a good education; however, many young college men find employment in this way. This opportunity should not be passed over lightly, certainly not without first making inquiry.

Fourth choice: personal interviews. Make a systematic survey of firms doing the type of work in which you are particularly interested. Call at the head office and state that you have a personal matter to discuss with Mr. —, the chief engineer. If he is out, ask for an appointment. If the firm is located at some distance, write a letter requesting an appointment for an interview. State that you are a recent college graduate and desire to discuss the general possibilities for young men in their particular field of activity. Never ask for an application blank. To ask outright for a job is to invite a curt letter: "*In reply to your recent communication, kindly be advised that there are no vacancies at the present time, and we anticipate none in the immediate future.*"

The Engineering Approach

Systematic research on the job question requires time, patience, and ingenuity. Attack the problem as you would any engineering task. Sit down and think out various approaches. Try them all. Keep carbon copies of all your letters, and study the replies, comparing the results of the various strategies employed. Constantly strive to improve your letters from the standpoints of grammar, forcefulness, tact, and style. The temper of the successive replies gives a measure of your accomplishment.

It is difficult to obtain the names and exact addresses of the best men to contact. Some possible sources of information are the Buyers' Reference Number of *Electrical World;* such buyers' guides as MacRae's Blue Book, Sweet's Catalogue Files, ASME Mechanical Catalog, Chemical Engineering Catalog; the classified telephone directory of your city. In looking for a position in the West, you may find helpful the April 1939 issue of *Electrical West,* which contained a directory of the western offices and representatives of electrical manufacturers doing business in that area. Those interested in government positions will find names, titles, and addresses in the Official Register of the United States: Directory of Federal and State Departments and Agencies, published for each state, and also in various state registers and directories. These may be found in most large libraries. Inquire at the document division.

References

The subject of references brings to mind this simple interview. *Prospective employer:* "Have you any references?" *Applicant:* "Surely, here is a letter, '*To whom it may concern: This man worked for us for one week and we are satisfied.*' "

I suggest that you prepare a list of men who know you and think enough of you to write letters on your behalf. Discuss the situation with each one of them, and get their consent before giving their names as references. Keep a record of the number of times you give each name. Obviously, to give the same list of references repeatedly will lead eventually to boring letters of recommendation.

Application Blanks

The problem of references and personal history should not be left to the last minute. To sit and ponder over an application blank in some prospective employer's office while trying to recall exact dates of past employment, the date of your birth, your mother's maiden name, and other data, is likely to make a very poor impression. This can be avoided by a carefully compiled personal history or biography. List all past employment, full- and part-time. Be sure to include the first name or initials, title, and correct address of your immediate superior for each employment listed. Part-time work which helped to pay your way through college should be included—it indicates your determination to get ahead in spite of adverse circumstances. Select a good recent snapshot of yourself and have several copies made. Sign and date each picture at the bottom to identify them if they should become detached and lost from subsequent application blanks. In other words, start your personal file, and keep a permanent record of the important events in your life.

Personal Appearance

For a moment place yourself in the position of a man interviewing laborers for ditch-digging. Would you employ a man who called at your office in formal dress and had a wishy-washy handshake? The answer is "no!" You would hire a man who appeared in the clothes of his calling and who shook hands like a man. Apply

the same principle to yourself. You have passed the college boy stage. You are a gentleman, seeking a place in industry along with other gentlemen. This calls for a hair cut, a shoe shine, and the substitution of a good business suit and a freshly laundered shirt for the college corduroys. Do not overdress. Overdressing makes as bad an impression as being slovenly.

Never seek an interview when you are depressed and feel that there is no hope left, for the simple reason that emotions are reflected in facial contours, voice, and spirit. When you feel discouraged over your failure to find work, take the day off, and force yourself to postpone further consideration of the subject for the present. Start with the thought that history repeats itself, and countless young men before you have found positions to their liking. If this does not produce an optimistic trend of thought, go to the nearest library and read Rudyard Kipling's "If."

Selecting an Employer

I am often asked to compare the opportunities of the large company with those of the small concern. I think relative size is unimportant in itself. The more important consideration is the comparative financial position of the companies in question. Compare their records in some reliable financial guide, such as Moody, Poor, or Fitch. Check the ratings given to the bonds, debentures, and stocks. Note the number of times interest was earned for bonds, and the earnings per share for stocks. Compare the earnings per share with recent stock dividends. This study will indicate both the relative condition of the companies and the latest trends of the business. Each individual must work out his own conclusions, but the following are submitted for consideration. For completeness, a discussion of working for the government is also included.

A. Prosperous Large Company

1. Probably low pay at the start.

2. Possibility of a new man's getting stuck on a routine job, or getting lost in a remote district.

3. Broad experience in a limited field.

4. Room at the top. There are many executive and semi-official positions that pay very well.

5. Large companies generally handle many lines. Through diversification the business is stable and depression resistant.

B. Prosperous Small Company

1. Probably good pay at the start.

2. Possibility of keeping moving and growing up with the company.

3. Limited experience in a broad field.

4. Executive jobs are few, and pay moderately. You may find that you will have to attend several funerals before there is a place for you at the top.

5. Small companies are generally very responsive to business conditions. The characteristic response is described by the phrase "either a feast or a famine."

C. Company in Financial Trouble

1. Probably fair pay at the start.

2. Promotions frozen.

3. You may find a spirit of discontent or sabotage prevalent.

4. Since you were among the last men hired, any slump in business is an excuse for letting you out. You may feel that you have no security, and you may be looking for a new position at a most unfavorable time.

D. Working for the Government

1. Best pay at the start.

2. First few promotions automatic, but later promotions tend to be frozen.

3. Your position may turn out to be a political football.

4. Stable and depression proof.

With reference to working for the government, it might be well to state that a great many thoughtful men think the salvation of our present form of government depends very largely upon the election and employment of honest, technically trained college graduates. It is indeed unfortunate that this field is overworked by one class and to some extent underrated by those capable of rendering the highest type of service.

Teaching

A few remarks regarding teaching as a profession may be in order. There are always opportunities for a limited number of young college graduates as assistants, particularly in laboratory courses. It is the writer's opinion that these positions should be considered temporary financial aids, or subsidies, for the purpose of obtaining higher degrees. To accept such a position as permanent, especially when there is no opportunity to work toward a higher degree, will probably result in disappointment. There is a growing and justifiable demand that the important positions in the educational field be filled by persons having advanced degrees or a very considerable amount of practical experience, preferably both. For such persons teaching provides a rare opportunity for service in training youth, and occasionally the satisfaction of making original contributions to technological progress and civilization. Those qualified will find the remuneration adequate, although possibly slightly below that obtainable in industry during normal times.

The following remarks, although not pertinent to the immediate problem of finding employment, are so closely related that they should be included. In this country you have the right to say and do what you please within much wider limits than are permitted anywhere else in the world. We all admire the man who acts in accordance with his convictions. However, remember that your employer had his share of trouble in keeping his employees working in harmony before you became a member of the organization. Regardless of the merits of your case, if he finds that you are causing an increase in restlessness, he is likely to have his own cure for the upstart problem. You will do well to forget the majority of your grievances, and let time temper the rest. In a relatively short time you will be considered a seasoned and respected employee, and at the psychological moment you will find your immediate superior sympathetic and willing to discuss your troubles in the privacy of his office.

The following axioms are given in conclusion:

1. Never change positions unless you can do so at a gain in salary or social prestige, preferably both.

2. Eradicate from your memory the words to the graduating hymn, "WPA, here we come."

The fact that the present business recession is beginning to be accepted as a new normal prompts the suggestion that you accept the first technical position offered. Put your whole heart and energy into it with a solid determination to make good. You will soon find that you have put so much of yourself into your job that you have manufactured a keen interest in it. Make friends with colleagues, subordinates, and immediate superiors. Find out what they think of their prospects. Grin and bear it, and stick it out for about six months. If, after you have your own prospects fairly well estimated, you come to the conclusion that there is no future in this concern for you, remember that you were looking for work when you accepted the position. In the meantime you have gained three important advantages:

1. You have had some worth-while experience with both men and machines, and your bargaining power has been increased by this experience.

2. It is often easier to secure a new position when you are employed.

3. If nothing else, you do not have to accept the next offer in order to maintain regular eating habits.

The Federal Government and Research

By A. A. POTTER

Some 10,000 persons are employed in Government research work, the expenditure for which was $124,000,000 in 1937

INDUSTRIES that have made the most spectacular growth during the past 25 years are also foremost in research. American industrial laboratories employ 25,000 research workers and spend $100,000,000 a year for research in order to develop new methods, new machinery, and improved materials. Some industries appropriate two to four per cent of their gross income for research. Research is an integral part of any organization interested in efficiency, in long-range goals, and in linking the present with the future. Bankers are recognizing that the research program of an industry is a safe guide to the investment value of its securities.

From the earliest days of our national history the United States Government has conducted investigation, of a greater or lesser scientific character, in order to establish a sound basis for its legislative and administrative activities. Congress is not only a creator of research agencies, but is itself engaged, through its committees, in investigations mainly in the social-science field. The Federal Government has assumed responsibility for research with special reference to agriculture, national defense, the conservation of natural resources, and the development and maintenance of physical standards.

Research by the Federal Government comprises investigations in both the natural and social sciences, and their applications, including the collection, compilation, and analysis of statistical, mapping, and other data which may result in new knowledge.

The National Resources Committee, with the approval of the President of the United States of America, has made a survey of the relation of the Federal Government to research, and published its findings in December 1938, in a report entitled "Research—A National Resource." This article is mainly a review of that report.

During 1936–37 the United States Government expended 120 million dollars for research, or about one dollar per capita of its population; 70 million dollars were derived from general funds and 50 million from emergency funds. For 1937 the research expenditure was 124 million dollars, of which 54 million were derived from emergency funds. Government research expenditures in the social-science field have increased materially and involve about one-quarter of the regular funds and nearly all of the emergency research funds. One-half of one per cent of the federal budget is the average amount spent for research.

Investigations in agriculture predominate among the fields of governmental research with more than one-third of all the regular research funds devoted to agriculture, an increase of $2^1/_2$ times in 15 years. Next to agriculture comes research for improved military and naval equipment and techniques, which account for about one-fifth of the regular research expenditure. Aeronautical research represents one-eighth.

About 125 federal bureaus and independent agencies are engaged in some form of research and about the same

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number carry on no research. The list of government-research projects is large, but includes mainly the fields of agriculture, defense, weather interpretation, public health, physical and biological problems inherent in the public domain or federal possessions, mental health, crime control, life and culture of the American people, physical and biological research involved in international relations, population changes, economic indices, labor problems, standards of living, governmental finance, and determination of standards.

Constitutional Responsibility

The Federal Government is obligated to carry on research in fields in which there is a constitutional responsibility, such as national defense and the determination of standards; fields in which the Government performs essential regulatory functions, such as control of traffic in foods and drugs and supervision of power production; fields in which extensive administrative or construction functions have become a federal responsibility, as in flood control and highway construction; fields in which the major problems are of a definitely national or interstate character, like agriculture, weather forecasting, and fisheries; and fields of research that lead to new products for which there is no market, except in war time, and no incentive for private industry, except to the extent that it is federally subsidized.

The Federal Government is also better equipped to carry on research that is very costly, such as aeronautic research, investigations and surveys in geology, geodesy, mineral technology, public health, and soil conservation.

The authority, prestige, and resources of the Federal Government may be used to organize and direct research in any given field on a national scale. Agricultural research, for example, is co-ordinated through state experiment stations. The War and Navy departments keep continuously informed as to developments in industry. The National Advisory Committee for Aeronautics, through its laboratory, serves as a central research plant for both industry and government alike.

The work of state agricultural experiment stations is an example of effective decentralized research stimulated by and carried on in close co-operation with government. The Public Health Service maintains relations with medical schools and with state boards of health.

During the Civil War, the National Academy of Sciences was chartered to make available to the government the talents of the scientific men of the country. During the World War, the National Research Council was organized to supplement the National Academy of Sciences in bringing to the government the services of the nation's research workers in natural science, anthropology, and psychology. The division of cultural relation of the Department of State is intended to bring about intellectual co-operation between this and other countries.

Progress demands new standards, new kinds of measurement, and ever-increasing accuracy. The Bureau of Standards performs these functions for the benefit of industry, the Government, and the public at large.

The numerous activities of the Department of Agriculture have grown up invariably in response to demands from farmers for assistance in solving practical problems that could not be handled by individual effort. Agriculture is a major industry which is nationwide in scope. The Department of Agriculture is the largest single research organization in the world and is the center of agricultural research. Through field laboratories, grants-in-aid, extension activities, and co-operative relations with federal, state, and private agencies, the department in a measure directs all research work in agriculture. There are 7,500 research workers in the department and in state agricultural experiment stations who are active in improving agriculture. Each state receives a grant of $90,000 for agricultural research in addition to its proportionate share under the Bankhead-Jones Act of 1935, which will reach three million dollars by 1940. States more than match federal grants for agricultural research.

The basic act for agricultural research is the statute creating the Department of Agriculture in 1862 and setting it up as a research agency. The creation in 1884 of the Bureau of Animal Industry extends this function. Then follows the Hatch Act, 1887, extending federal support to states for agricultural research. The Adams Act of 1906 allows additional agricultural research funds. The most recent legislation is the Bankhead-Jones Act of 1935, which is an amendment to the Land-Grant College Act "to conduct research into laws and principles underlying basic problems of agriculture in its broadest aspects."

The Forest Research Act, or the McSweeney-McNary Act, of 1928, is intended to encourage forestry research.

A closely knit, highly centralized form of organization is typified by the Navy Department. All its activities are pointed toward the single end of national defense. National defense requires constant research to develop new weapons and improved materials of war.

The National Advisory Committee for Aeronautics was created by Congress in 1915 and is mainly a research agency. It has the largest and best equipped aeronautical research laboratory in the world at Langley Field, Va. Leading foreign countries have sent aeronautical missions to this country to study NACA research organization and laboratories.

The Geological Survey is the largest contributor to geological science, and the results of its findings are of value to the mining and petroleum industries, as well as to those concerned with the construction of highways, bridges, water storage, and similar works. River flow and investigations of wells are within the field of the Geological Survey.

The Bureau of Mines is national in scope in its relation to mining and metallurgy. It grew out of the Geological Survey and is intended to carry on scientific and technological investigations in mining.

The Coast and Geodetic Survey maps coast lines, investigates tides and currents, and makes geodetic control surveys on which surveying and mapping operations depend.

Governmental research has acted in many cases as a

stimulus to industry; examples of this are nitrate fertilizer research by the Bureau of Chemistry and Soils, boiler scaling and embrittlement of boiler steels by the Bureau of Mines, and the new industries that have grown out of the work of the Bureau of Fisheries on oil and fish-liver oils. The Navy Department has been an important factor in developing the steel industry through its insistence on steel plates for battleships as early as 1883. Steel castings were first made in this country in 1887 to meet Navy requirements.

The Social Security Board is expected to carry on investigations in the fields of old-age pensions, unemployment, accident compensation, and the like.

Regulatory Commissions Sponsor Research

Regulatory commissions, which have as their primary functions regulation rather than research, sponsor research as an important activity. Thus, the Interstate Commerce Commission has authority to "inquire into the management of the business of all common carriers." The Federal Trade Commission is empowered to "investigate the organization, business conduct, practices, and management of any corporation engaged in commerce. Its activities encompass foreign countries as well as the United States.

The National Bituminous Coal Commission is expected "to conduct research designed to improve methods used in the mining, preparation, conservation, distribution, and utilization of coal, and the discovery of new uses for coal."

The fields of research open to the Federal Power Commission, Bituminous Coal Commission, Maritime Commission, Federal Communications Commission, and other agencies are as fully specified as are those of the Bureau of Reclamation, Rural Electrification Administration, Vocational Educational Board, and the Civilian Vocational Rehabilitation Board.

The Tennessee Valley Authority is authorized to undertake "experiments for the purpose of enabling that corporation to furnish nitrogen products for military purpose and for agricultural purposes." Other research agencies are the Federal Housing Administration, Federal Reserve Board, Bureau of Census, Bureau of Foreign and Domestic Commerce, and the Tariff Commission.

The Bureau of Census furnishes social-science data and carries on social-science research of great value to the public. The Congressional Library aids the collection and interpretation of research information.

About 10,000 persons are employed in research positions with the Government. In 1896 only about 2.3 per cent of the civilian positions in executive civil services involved professional, scientific, and technical functions as contrasted with 12.7 per cent in January 1937. From 1931 to 1937 social-science research workers under civil-service classification have increased 17.28 per cent as compared with 9.31 per cent in the physical sciences. The recruiting, placement, and in-service training of research workers in the Government are not as satisfactory as in industry or higher educational institutions. Most of the investigators in the Government bureaus are selected from civil-service lists and at salaries of $2,000 to $9,000 per year. The present civil-service procedure places the Government at a disadvantage in recruiting and in holding the highest type of scientific and technological personnel in competition with industry, universities, or other scientific agencies. The Government, in most bureaus, fails to train its promising young research workers in newly developed techniques.

The bureaus and agencies of Government have the privilege of going outside the civil service for the employment of experts in a consulting capacity or to investigate special problems. The compensation of such experts varies from $10 per day in the Bureau of Mines to $50 per day in the Bureau of Reclamation. Advisory committees, such as the visitors of the Naval Observatory or the visiting committee of the Bureau of Standards, serve without pay.

Any consideration of the relation of the Federal Government to research is incomplete without some mention of what is done by colleges and universities, particularly those supported by public funds. All research agencies, including the Government, must rely upon higher educational institutions for research personnel and for leadership in pure research. In 1867 only 25 universities conferred doctor of philosophy degrees, and 44 such degrees were conferred that year; 2,709 were conferred by 86 institutions of higher learning in 1937. One-quarter to one-third of those who receive the doctor of philosophy degree continue in research.

A large part of the research in universities is independent and unorganized, controlled directly or chiefly by the interests of the individual professor. Of the 1,450 American colleges and universities, 150 expended for all purposes during the year 1935–36 about 265 million dollars, and of this about 50 millions were spent for research. The remaining 1,300 spent a total of 155 million dollars and about 1 million for research.

About one-quarter of the income of 20 leading universities is claimed to be spent for research. Those spending more than 2 million dollars per year are: California, Chicago, Columbia, Harvard, Illinois, and Michigan; $1\frac{1}{4}$ to 2 million: Cornell, Minnesota, Wisconsin, and Yale; 1 to $1\frac{1}{2}$ million: Massachusetts Institute of Technology, New York University, Ohio State University, and University of Pennsylvania; $\frac{1}{2}$ to 1 million: Purdue University, Iowa State College, Iowa University, Pennsylvania State College, Texas Agricultural and Mechanical College. In many of the institutions the agricultural-experiment-station funds aid in making the totals appear conspicuous. In most land-grant colleges and universities little research, outside of agricultural research, is done.

An unbiased analysis of the research activities of our Government leads one to conclude that the scientific contributions of the 125 bureaus and independent agencies are of high order and of distinct benefit to agriculture, national defense, and the public at large. There is need for more scientific research by government to control national defense, to create new opportunities for employment, to improve the products of the farm and shop, and to raise living standards.

Power Requirements in Electrochemical, Electrometallurgical, and Allied Industries

Electrochemical and electrothermal processes consume electric power in such large amounts as to warrant special consideration with respect to the supply of electric energy produced to meet the growing needs of the United States. This presentation summarizes the past and present use of electric power in the electroprocessing industries, and considers the probable effect of economic trends and the development of new processes and products upon their future power requirements

ELECTROCHEMICAL and electrothermal processes, separately or integrated with other operations, play a large part in the manufacture of products that touch the daily life of every individual. Some of these products can be obtained by no practical means except electric power; others are perfected or improved or given special characteristics by electric processing. Some are classed as strategic materials, essential for the national defense. Some are in common use; others assist or make possible the manufacture of important commodities.

The investigations upon which data here contained are based covered the more important industries and processes using electric power primarily for electrolysis or for heat. The electrolytic group includes the production of aluminum, copper, zinc, magnesium, cadmium, and certain other metals; and of chlorine, caustic soda, and hydrogen peroxide. The electrothermal or heat group includes the application of electric furnaces to the melting, refining, alloying, and heat-treating of iron and steel, brass, and ferroalloys; the manufacture of abrasives, refractories, calcium carbide, carbon products, and phosphoric acid. The processes for chemical nitrogen, potash, and inorganic fertilizers were included in the study because they are related to various electrochemical operations and are of similar significance to the development of power markets and power resources.

Information on the consumption and supply of electric power was compiled largely from statements by the industries and by electric utilities, supplemented where necessary by estimates based on various published and unpublished data. Some of the figures on the capacity of power equipment installed were supplied by manufacturers of equipment. The period covered, in general, is 1926 to 1936.

Location of the Industries

Electrolytic and electrothermal plants for the most part are located where hydroelectric energy is available in quantity at low cost. Representative of this are the large establishments at Niagara Falls and Massena, N. Y., Keokuk, Iowa, Sault Ste. Marie, Mich., Alcoa, Tenn., Badin, N. C., and Tacoma, Wash. Among the exceptions are the arc and resistor furnaces for iron and steel, located according to product requirements; and the electrolytic copper refineries on the Atlantic seaboard, which are near the large markets for copper in the brass and electrical industries of New England and the Middle Atlantic states, and also convenient for the refining in bond of foreign ores and concentrates received by water.

Figure 1 shows the location of the major electrolytic industries in the United States. Widespread but individually small operations in electroplating, electrotyping, the electrolytic production of hydrogen and oxygen, and the electrolytic production of chlorates are not shown, because these processes are parts of other and larger industries and have as yet been of relatively little significance to power.

The electrothermal processes cannot adequately be presented in a single map. Figure 2 shows the location of the direct and indirect arc furnaces for melting and refining iron and steel. The installations are grouped according to industrial districts and include 571 units having an aggregate capacity of 805,667 kva. A striking fact revealed by this map is that the equipment is not concentrated in iron and steel centers alone, but is widely distributed wherever machinery, tools, and motors are made. No fewer than 21 localities contain electric-furnace capacity of 10,000 kva or more.

Figure 3 shows the electric-furnace ferroalloy industry of the United States. The effect of available low-cost electric power may be noted particularly in the locations of plants at Niagara Falls, N. Y., Keokuk, Iowa, and Alloy, W. Va.

The installations of induction furnaces are shown in the listings of table I. Relatively small both in tons capacity and rated kilowatts, these furnaces are of growing importance to the brass and alloy steel industry.

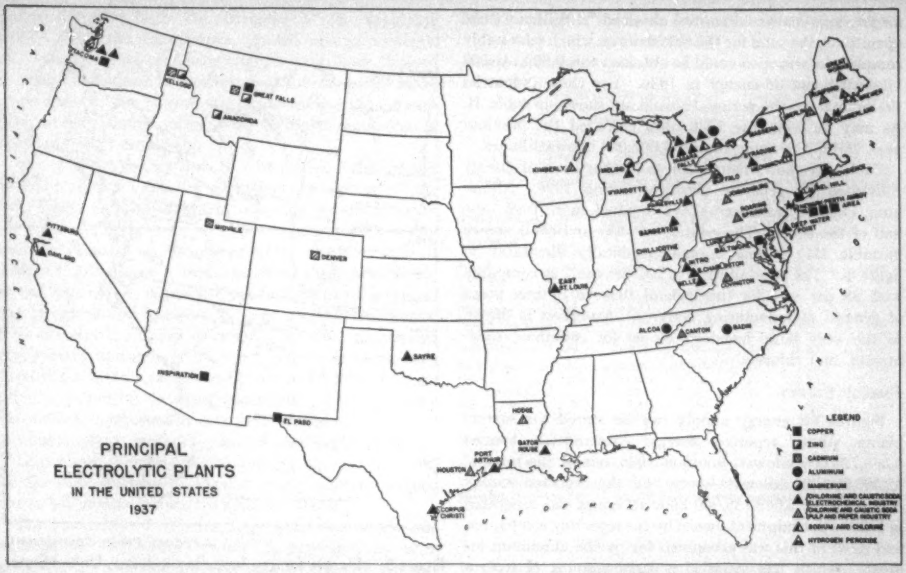
Power Requirements and Supply

Energy Consumption

In 1936 the products and processes covered by this report consumed about 12,500,000,000 kilowatt-hours of electric energy, equivalent to more than ten per cent of the total energy generated for public use in the same year. This figure for the year 1936 includes 105,000,000 kilowatt-hours for electric-furnace iron, 2,200,000,000 kilowatt-hours for electric heat treating, and 600,000,000 for miscellaneous small operations on which adequate data

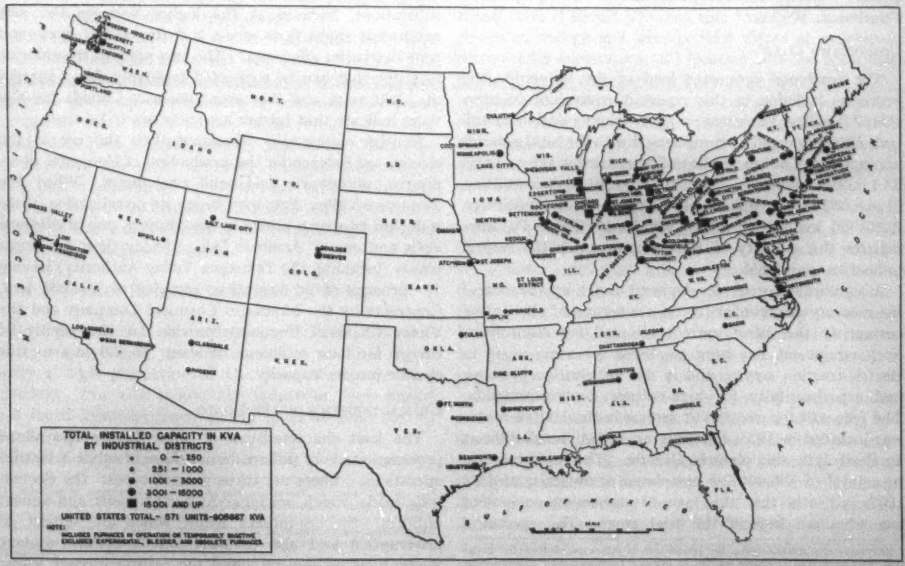
Abstract of the report of the same title published by the Federal Power Commission September 1938. The discussion follows closely an address delivered by James V. Alfriend, Jr. (A'33) at the AIEE summer convention, Washington, D. C., June 24, 1938.

1. For all numbered references, see list at the end of the article.



—*Federal Power Commission.*

Figure 1. Location of the principal electrolytic plants in the United States, 1937



—*Federal Power Commission.*

Figure 2. Location and capacity of electric arc furnaces for melting iron and steel, United States, 1937

for previous years could not be obtained.* Without these operations, the total for the industries on which reasonably complete information could be obtained was 9,609,141,000 kilowatt-hours of energy in 1936. For these industries the figures for the period 1926–36 are shown in table II. As may be seen, the 1936 total exceeded the previous peak of 1929 by more than 623,000,000 kilowatt-hours.

Table III shows figures for the segregation of energy consumed for separate products during 1936. Aluminum, chlorine, and ferroalloys required more than one-half of the total. The relation of 1936 to 1929 is shown in table III, column 6, and graphically illustrated in figure 4. The over-all ratio is 107 per cent, as compared with 88 per cent for the Federal Reserve System index of general manufacturing activity. Attention is drawn to the very large increases shown for cadmium, magnesium, and chlorine.

Energy Supply

Figures for energy supply can be stated for certain plants whose reported energy consumption totaled 4,588,726,000 kilowatt-hours in 1936, out of the total of 12,500,000,000 kilowatt-hours. Of the reported energy consumption, 2,669,788,000 kilowatt-hours was generated in 1936 with equipment owned by the reporting companies, and most of this was accounted for by the aluminum industry, which has installed a large amount of hydroelectric capacity in order to obtain its large requirements for power at low cost. Future increases in generation are to be expected in aluminum and also from new hydroelectric capacity for the production of ferroalloys near Charleston, W. Va.

Connected Load

The combined connected load of the industries and processes included in this report is equivalent to more than 3.8 million kilowatts—a figure whose relative magnitude may be gauged by comparing it with the total generating capacity of all the public utility systems in the country, 33.7 million kilowatts. (Privately owned electric utilities, 31,458,003 kw; municipally owned electric utilities, 2,225,986 kw; total, 33,683,989 kw.)[1] Table IV summarizes the capacity of the equipment for the several industries considered.

A significant recent development is the appearance of the mercury-arc rectifier for the conversion of alternating current to the direct current required for electrolysis. Such equipment has been employed for some years in electric-traction service and in d-c distribution systems, and experimentally for high-voltage d-c transmission. The first unit for electrolytic service in the United States was installed in 1934, following an earlier installation at an electrolytic zinc plant in Canada. The rapid increase to a total of 136,460 kw completed or on order in July 1937, indicates that this type of conversion equipment has advanced beyond the trial stage. The successful

—*Federal Power Commission.*

Figure 3. Electric furnace ferroalloy industry, United States, 1937

performance of the pioneer units at 500 to 600 volts may lead to a considerable change in the design of electrolytic substations, because at the higher voltages the new equipment saves floor space and foundation work and provides better efficiency. The two units in the chlorine industry that can be connected to supply direct current at 1,000 volts and the recent units in Canada for 830 volts indicate that further advances are to be tried.

Another noteworthy development is the use of the electric-arc furnace for the production of elemental phosphorus, phosphoric acid, and phosphates. When the Tennessee Valley Authority began its investigation, there were but two such plants in the country, one at Niagara Falls and one at Anniston, Ala. Today there are seven plants (including the Tennessee Valley Authority) having 19 furnaces of an aggregate capacity of 102,000 kva. Contracts by the Monsanto Chemical Company and the Victor Chemical Company provide for the supply of energy for later additions of about 66,000 kva to this electric-furnace capacity.

Characteristics of the Loads

The load characteristics of these highly specialized processes are very different from those of other industrial operations. There are three general types: the electrolytic loads, which are inherently continuous and almost uniform; the arc-furnace loads, which are subject to interruption and also to wide and sometimes violent fluctuations in demand; and the resistor-furnace loads, which are typically steady during the hours of operation.

The electrolytic and resistor-furnace processes are

* Electroplating, electrotyping, the production of chlorates, electrolytic oxidation, and reduction processes applied to organic chemicals, and miscellaneous electric-furnace operations. Individually these loads have been relatively small and they are distributed so widely as to place the collection of data beyond the scope of this investigation. The total consumption of energy in these operations is estimated roughly at 600,000,000 kilowatt-hours in 1936.

highly desirable from the viewpoint of the supplying utility. For the arc furnace, special control methods and arrangements of feeder circuits have been devised to keep the demand fluctuations within bounds and make it possible for the central station to supply the furnace load without undue interference with the regulation of service to other customers.

The electrolytic demand can be varied intentionally between certain limits by adjusting the voltage of the d-c supply, without materially affecting the efficiency of the cells. It is thus possible either to operate at a nearly uniform demand or to obtain other characteristics if desired. Advantage is being taken of these possibilities at the large copper refinery whose load curve for a typical day is reproduced in figure 5. The controllable electrolytic demand is utilized to smooth out the uncontrolled and varying demands of the other plant operations, thus obtaining a better over-all load factor and a lower average price for power for the plant as a whole. At this refinery the control equipment is actuated automatically by the combined plant demand. One of the larger producers of electrolytic chlorine has also installed automatic control for the same purpose.[2] Another copper refinery obtains somewhat similar results by manual control.

The possibility of utilizing large quantities of low-cost seasonal or "secondary" power† is suggested by such examples of load control and also by electric furnace operations at Keokuk, Iowa, and near Sheffield, Ala., where arrangements have been made for the use of secondary power at low rates for a portion of their requirements. The plants having such contracts produce ferroalloys, calcium carbide, or phosphates.

A further characteristic of the electrochemical and many of the electrothermal loads that may assist in fitting their requirements to available low-cost power is that they are typically made up of sequences of comparatively small equipment units whose output is not limited by other plant operations. Small-capacity plants may therefore show production costs not very different from larger ones, and in general the operations are more flexible and the rates of output can be varied with smaller losses in efficiency and less interference with operating schedules than in most large industries.¶

Cost of Power Related to Price of Product

In the electroprocess industries with their enormous power requirements, the cost of electric power is necessarily a high proportion of the price of the resulting products. For this reason the industries have sought and found locations where power could be generated or purchased cheaply.

Table V shows the relation of the cost of electric energy

† Power that is usually available but is not guaranteed as "firm" power. At some hydroelectric plants the firm output is governed by water conditions that occur only occasionally and can be predicted with some accuracy in advance, as for example by low water for a few weeks of an extremely dry season; and there are large quantities which are available at all other times but can not be guaranteed.

¶ The possibility of adjusting industrial operations to fluctuating hydroelectric output, instead of supplying steam-electric generating capacity, was discussed in ELECTROTHERMIC HYDRO-NOMICS, by **K. J. Gaudy**, *Transactions of The Electrochemical Society*, volume 70, 1936, pages 171–84.

Table I. Electric Induction Furnaces in the United States, 1936–37

State	For Melting Brass and Other Nonferrous Metals and Alloys, January 1, 1936			For Melting or Heating Stainless Steels and Other Special Ferrous Alloys[a] January 1, 1937		
	Number of Furnaces	Capacity		Number of Furnaces	Capacity	
		Pounds Charged	Rated Kilowatts[b]		Pounds Charged	Rated Kilowatts[b]
Connecticut	276	217,550	18,365			
Delaware	2	1,500	120			
District of Columbia	1	750	60	8	5,050	500
Illinois	40	30,000	2,595	2	16,000	1,200
Indiana	1	100	60	1	100	60
Kentucky	17	12,750	1,035			
Maryland	6	4,500	360			
Massachusetts	6	4,500	390	7	16,050	900
Michigan	49	42,050	3,405	6	2,000	510
New Jersey	22	21,400	1,480	17	15,900	1,650
New York	44	33,600	2,970	7	3,900	570
Ohio	11	12,450	1,055	12	13,300	2,125
Pennsylvania	12	10,850	945	23	16,542	2,500
Rhode Island	2	300	100	3	960	150
Wisconsin	25	18,750	1,515	1	100	60
Total	514	411,050	34,455	87	89,902	10,225

a. Includes three installations also melting brass.

b. Brass furnaces are rated according to individual units; steel and heating furnaces according to the capacities of the motor generators supplying each installation or group of furnaces.

to recently prevailing prices or values for some of these products, at assumed energy rates ranging from one mill to one cent per kilowatt-hour. Where available, actual average energy rates known to have been paid by representative producers are given. In considering these actual rates it should be noted that average unit costs of generated energy and average unit prices of purchased energy differ according to the location and also according to the quantity and characteristics of use in any one plant.

Taking electrolytic zinc as an example, 0.25 and 0.5 cent are shown as representative average rates which have been paid by producers in the field. At 0.25 cent, the cost of power is about 9.3 per cent of the selling price of the zinc. At 0.5 cent it is 18.6 per cent.

In most cases the typical price paid for electric energy happens to result in a ratio of energy cost not far from ten per cent of the product price or value. Rates providing a lower ratio than this are naturally acceptable to the industry, but successful commercial practice indicates that so far they have not been absolutely necessary. Lower rates would presumably encourage more extensive development; with some exceptions, higher rates have apparently prevented any development.

In general these ratios of energy cost to product value are several times as large as in other manufacturing industries, where the power cost is often about two per cent. But other factors must be considered, including the cost of raw materials and labor, transportation and marketing facilities, and especially the value of the electric process in reducing other costs and in obtaining co-products or by-products. Power is relatively so important in the aluminum industry, for example, that the reduction plants have been established in regions where energy can be generated at a cost of less than three mills per

kilowatt-hour; on the other hand, electrolytic copper-refining plants with their smaller power requirements have purchased energy at average rates as high as 1.5 cents per kilowatt-hour. Plants in the ferroalloy industry purchase energy at three or five mills per kilowatt-hour

Table II. Energy Consumed in Thousands of Kilowatt-Hours[a]

Year	Total	Electrolytic	Electrothermal	Motors and Lighting[b]
1926	4,121,080	2,546,454	703,095	871,531
1927	6,781,959	3,407,228	2,342,685	1,032,046
1928	5,090,556	3,306,636	834,141	949,779
1929	8,985,978	4,436,458	2,957,186	1,592,334
1930	7,236,431	4,048,060	1,861,206	1,327,165
1931	5,748,807	3,109,246	1,605,397	1,034,164
1932	3,400,979	1,943,715	703,093	754,171
1933	4,501,059	2,230,327	1,399,762	870,970
1934	4,738,858	2,111,445	1,377,757	1,249,656
1935	6,973,387	2,919,527	2,446,161	1,607,699
1936	9,609,141	4,359,683	3,312,833	1,936,625

a. Does not include chlorine, 1926 and 1928; brass, etc., 1926 to 1933, inclusive; calcium carbide, 1926–28–30–32–34; electric furnace iron, all years; electric heat treating, all years.

b. Includes total requirements for chemical nitrogen, potash, and inorganic fertilizers.

and still their power cost is 21.3 to 44.3 per cent of the product value; electroprocessing is here used for product characteristics unobtainable by other means.

Product and Process Competition

Direct competition exists between electric furnaces and fuel-fired furnaces for many purposes, affected in some regions by the availability of raw materials and the accessibility of markets. Each type of equipment has its most suitable applications. In some operations the technical or operating advantages of the electric equipment outweigh the extra cost; in others, cost is the primary consideration. Where economy governs, future developments will depend on comparative prices of fuel and electric power.

In the copper industry, electrolytic refining and reduction for years has accounted for 90 per cent of the domestic production of primary refined copper, and no change in this relationship is in sight. In the production of pure zinc the electrolytic reduction process experienced a rapid growth and then apparently stabilized at about one-fourth of the domestic total; the remainder is produced in fuel-fired retorts. With the increasing demand for high-purity zinc in brass and die castings and the recent introduction of electrogalvanizing, and with decreasing electric rates, a resumption in the growth of the electrolytic zinc process is expected.

In the melting of brass for rolling and casting, electric induction and arc furnaces have already largely superseded fuel-fired equipment. In the large and important field of heat-treating, the capacity of electric furnace equipment has increased from 12,000 kw in 1920 to 770,773 in 1937. The electric equipment possesses definite advantages in accuracy of temperature adjustment, adaptability to modern "line" production, and the possibility of controlling the gases within the furnace. The success of "bright annealing" and continuous annealing illustrates the effect of these special technical advantages. Electric resistor furnaces have displaced many fuel-fired furnaces for these purposes, in spite of higher first costs and relatively high operating costs. With the present downward trend in equipment cost made possible by better design and better materials, and progressive rate reductions made possible by lowered electric costs and improved load characteristics, it appears reasonable to expect a continued increase in installations of electric heat-treating equipment.

In several relationships in the marketing of electroprocess products, competition has definitely increased the consumption of electric energy required for one or both of the competing materials. For example, aluminum has made considerable progress as a material for electric

Table III. Consumption of Electric Energy in Electrochemical, Electrometallurgical, and Allied Industries, United States, 1936[a]

Principal Product	Consumption of Electric Energy (Thousands of Kilowatt-Hours) Total	Process: Electrochemical	Process: Electrothermal	Motor and Lighting	Ratio of Total (2) 1936 to 1929 (Per Cent)
	(1)	(2)	(3)	(4)	(5)	(6)
Electrolytic:						
Aluminum[b]	2,597,000	2,217,367	0	379,633	93.0
Copper[c]	651,317	282,856	633	367,828	61.1
Zinc	514,895	445,876	0	69,019	83.0
Cadmium	3,916	3,275	0	641	148.1
Magnesium	39,033	35,130	0	3,903	429.7
Chlorine and caustic soda[d]	1,568,415	1,375,179	0	193,236	149.5
Electrothermal:					
Electric furnace steel[e]	743,000	0	743,000	[e]	96.5
Electric furnace ferroalloys	1,752,000	0	1,668,571	83,429	126.0
Brass and other nonferrous alloys[f]	415,835	0	149,466	266,369	[g]
Artificial abrasives	87,357	0	65,489	21,868	89.0
Calcium carbide	550,000	0	523,810	26,190	77.5
Carbon and graphite products	195,663	0	161,864	33,799	181.1
Allied Products:					
Nitrogen	288,000	0	0	288,000	138.5
Potash	83,710	0	0	83,710	378.5
Fertilizer	119,000	0	0	119,000	85.0
Total	9,609,141	4,359,683	3,312,833	1,936,625	106.9

a. Figures for 1936 from Table I, Consumption of Electrical Energy in Electrotechnical, Electrometallurgical, and Allied Industries, United States, 1926–36, Section 1, Power Requirements in Electrochemical, Electrometallurgical, and Allied Industries, Federal Power Commission, 1938. Data are partly estimated.

b. Includes mining of domestic ore, production of primary ingot from domestic and imported ore, and fabrication of both imported and domestic ingot, sheet, etc. Includes estimates covering the small proportion consumed in fabricating plants operated by companies not associated with the major producer.

c. Includes energy used in associated mining, milling, and smelting activities of one company in Montana and one in Arizona. Consumption includes energy used in the production of gold, silver, copper oxide, white lead, white metals, and other metallic pigments, tin products, solder metal, arsenic, acid, phosphate fertilizers, and other products not separately reported.

d. Includes caustic potash, metallic sodium, electrolytic soda ash, and hydrogen peroxide.

e. Small amounts of energy for motor and lighting loads associated with these operations are neglected.

f. Includes melting, founding, or fabricating copper, brass, or bronze.

g. Data are not available.

transmission lines—a field previously occupied exclusively by copper. But copper is used in the electric equipment required for producing aluminum, and also in transformers and other facilities at each end of an aluminum transmission line. Opinions differ as to which material is best suited for the various types of line, but it is clear that advantage will be taken of the special characteristics of each metal and that they will assist each other in serving the electric needs of the country. Among the results will be a larger consumption of electric energy in the production, refining, and fabrication of the two metals than would be required for copper alone.

Electric-arc welding supplied an important stimulus to the fabrication of structures and machinery by welding instead of by the assembling of riveted parts of castings. As a result the use of acetylene for welding and flame-cutting has also greatly increased, in spite of the active competition of the electric welding equipment. Acetylene is made from calcium carbide, an electric-furnace product. Probably neither electric welding nor acetylene welding could have reached its present development without the other, and electric energy is a requirement of both.

High-speed light-weight transportation equipment on rail and highway, in the air, and on the water is employing aluminum, magnesium, and high-alloy steels.[‡] All three are products of electroprocesses. Aluminum and magnesium provide light weight by reason of their low densities; alloy steels, such as stainless steels, furnish light weight because their strength and resistance to corrosion permit the use of thinner sections. In these applications, the three types of material have been competing in a developing field, but the effect has been to stimulate keener commercial and technical rivalry rather than to limit the growth of any of the several products. All three types may be expected to be combined in light-weight equipment and structures, each in its most suitable application, with the results of better construction, an improved market for the metals, and also greater requirements for electric energy in their production.

Electroprocess Equipment as an Industrial Tool

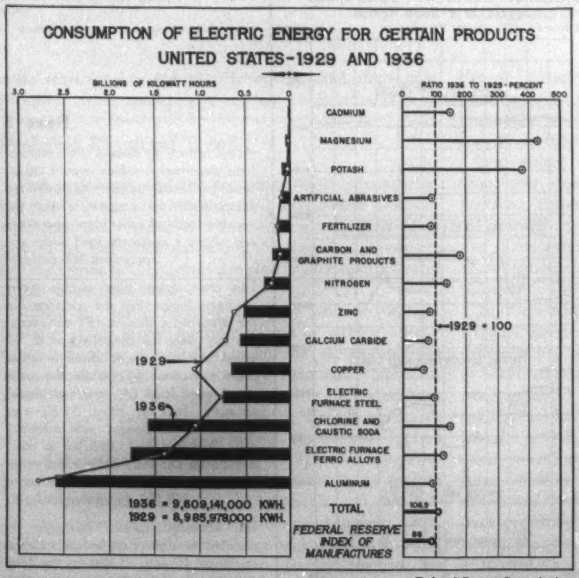
The electrolytic cell and the electric furnace, pot, or oven are adaptable to either large-scale or small-scale operations. In addition to the large units required for the basic operations of the electroprocess industries, such equipment is being widely applied as a tool or auxiliary in other industries. Installations range from the solder pot of a few hundred watts in capacity to the electric arc furnace of 20,000 kva.

Examples of these applications are the electroplating operations of large electrical and automobile manufacturing establishments; electric furnaces and ovens in mills and foundries for iron, steel, brass, and other metals; the electrolytic cleaning of sheet metal in the same plants; and the electrolytic production of organic chemicals. The future development of such uses of electroprocess equipment as a tool in other industries may bring increases in energy requirements as great as the corresponding increases in the electroprocess industries themselves.

New Processes and Products

The electrochemical and electrometallurgical industries have been marked by constant change throughout their relatively brief history. Research workers have found these fields extremely fruitful and have steadily added to the list of products and processes that contribute to modern needs and affect the consumption of electric energy. These developments are continuing on a broader base.

During the past eight years research has produced striking results in the field of powder metallurgy and in the production of rare and minor metals in electric furnaces and electrolytic cells. The need for high-speed cut-



—*Federal Power Commission.*

Figure 4. Electroprocess industries consumed more energy in 1936 than in 1929, and showed a higher ratio of increase than general manufacturing (compare table III)

‡ Railroads in the United States have placed in service 78 cars built largely of aluminum alloys, 79 cars largely of stainless steel, and 36 of other alloy steels, operating in more than 40 trains described as streamlined, high-speed, etc. R. L. Kimball, based on data published in *Railway Age*, November 1934 through June 1937.

Table IV. Capacity of Installed Power Equipment

Generating equipment:[a]	
Hydroelectric	583,400 kw
Steam-electric	227,994 kw
Internal combustion	2,005 kw
Total	813,399 kw
D-c equipment for electrolysis:	
Rotating conversion equipment	644,875 kw
Mercury-arc rectifiers	136,460 kw
D-c generators[b]	107,795 kw
Total, d-c equipment	889,130 kw
Electric furnace equipment:	
Arc resistance and induction furnaces	1,493,077 kva
Resistor furnaces and ovens	770,773 kw
Mechanical drive equipment (other than generators):	
Electric motors	951,148 hp
Steam engines and turbines	60,499 hp
Internal combustion engines	200 hp
Total, mechanical drive	1,011,847 hp

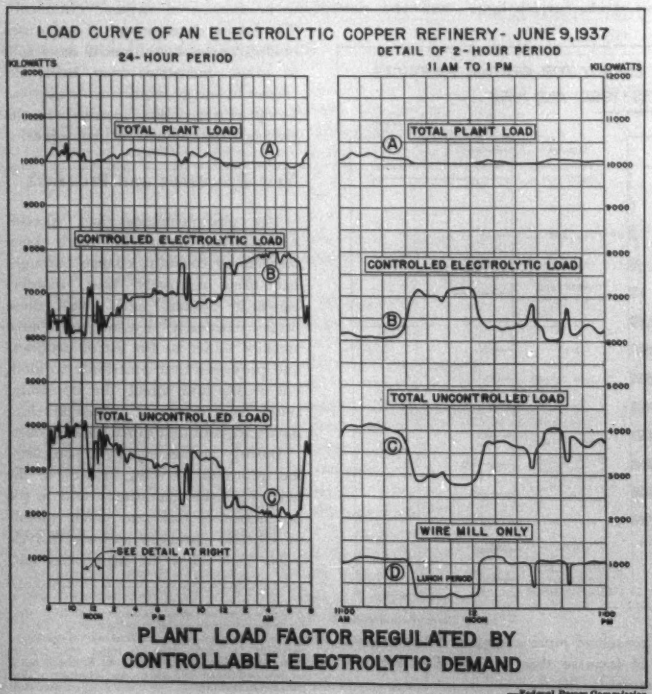
a. The installed capacity of generating equipment is given for all of the products and processes included in the Federal Power Commission report, except chlorine and caustic soda, electric steel and iron, and inorganic fertilizers.

b. Included in the capacity of generating equipment.

ting tools that would retain their hardness even at red heat has brought about the development of a growing list of metal carbides which are produced in electric furnaces, powdered, and then sintered in another type of electric furnace with a binder such as cobalt. Some of these materials approach the diamond in hardness.

The United States Bureau of Mines, as well as other public and private agencies, is developing new processes utilizing electric energy and domestic raw materials. One of these obtains manganese by electrolysis from domestic low-grade ores; another obtains alumina, silica, and potash from domestic alunite ore by an electric-furnace method. Carbon bisulphide, silicon, fused silica, fused quartz, phosphoric acid, and phosphorus are among the electric-furnace materials whose combined production has as yet required relatively small quantities of electric power. Phosphates have assumed considerable significance within the last three years. Decreasing power rates may have an important bearing on the quantities of these and other materials produced electrically, and therefore on the consumption of electric energy.

These are but examples of the many new processes and new products already in laboratory or pilot plant or early commercial stages of development. Many others have appeared or are on the technical horizon. Not every one of these can be expected to succeed commercially as have aluminum, stainless steel, and electrolytic copper. But it would be surprising if there are not several that will rival the present importance of these materials in



—Federal Power Commission.

Figure 5

At this refinery the demand of the electrolytic department—which would otherwise be almost uniform—is controlled automatically to compensate for the variable loads of other plant operations and obtain a combined load factor approaching 100 per cent

This chart, taken from graphic meter readings, shows that the variations in the electrolytic demand (*B*) throughout the day were so controlled as to be equal and opposite to those in other plant operations (*C*), while the combined plant load (*A*) remained almost constant. Thus at about 11:30 a.m. the electrolytic demand was automatically increased by 1,050 kw to compensate for the sharp drop in the other loads that occurred when the wire mill (*D*), shut down for lunch

The automatic control equipment is actuated through relays by the variable combined demand; it changes the field excitation in the motor generators that supply the d-c energy for electrolysis, which in turn changes the d-c voltage and therefore the power drawn by the cells

Table V. Cost of Power Related to Price of Product (Power Costs of 5 to 15 Per Cent of Selling Price Are Shown in *italics*)

Product (1)	Unit of Measure (2)	Unit Selling Price (Dollars)[a] (3)	Unit Electric Energy Requirements (Kilowatt-Hours)[b] (4)	Ratio (Per Cent) of Electric Energy Cost to Selling Price of Finished Product at Selected Average Unit Costs of Energy (Cents per Kilowatt-Hour) 0.1 (5)	0.2 (6)	0.25 (7)	0.3 (8)	0.35 (9)	0.4 (10)	0.5 (11)	0.6 (12)	0.7 (13)	0.8 (14)	0.9 (15)	1.0 (16)	Energy Costs of Representative Producers (Cents per Kilowatt-Hour) (17)
Electrolytic:																
Aluminum	Short ton	400.00	23,988	*6.0*	*12.0*	*15.0*	18.0	21.0	24.0	30.0	36.0	42.0	48.0	54.0	60.0	[c]
Copper (electrolytic leaching)	Short ton	220.00	2,820[d]	*1.3*	*2.6*	*3.2*	*3.8*	*4.5*	*5.1*	*6.4*	*7.7*	*9.0*	*10.3*	*11.5*	*12.8*	0.65
Copper (electrolytic) refining	Short ton	220.00	367	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.2	1.3	1.5	1.7	0.70
Zinc	Short ton	100.00	3,714	*3.7*	*7.4*	*9.3*	*11.1*	*13.0*	*14.9*	18.6	22.3	26.0	29.7	33.4	37.1	0.25-0.5
Magnesium	Short ton	600.00	20,000	*3.3*	*6.7*	*8.3*	*10.0*	*11.7*	*13.3*	16.7	20.0	23.3	26.7	30.0	33.3	[c]
Sodium (metallic)	Short ton of metallic sodium and 3,083 lb of chlorine	376.28[e]	14,400[d]	*3.8*	*7.7*	*9.6*	*11.5*	*13.4*	15.3	19.1	23.0	26.8	30.6	34.4	38.3	0.35
Chlorine and caustic soda	Short ton of caustic soda and 1,770 lb of chlorine	109.16[f]	3,009	*2.8*	*5.5*	*6.9*	*8.3*	*9.6*	*11.0*	*13.8*	16.5	19.3	22.1	24.8	27.6	0.35
Electrothermal:																
Ferromanganese 80 per cent	Long ton	102.50	7,280[d]	*7.1*	*14.2*	17.8	21.3	24.9	28.4	35.5	42.6	49.7	56.8	63.9	71.0	[c]
Ferrosilicon 50 per cent	Long ton	69.50	6,160[d]	*8.9*	17.7	22.2	26.6	31.0	35.5	44.3	53.2	62.0	70.9	80.0	88.6	0.3-0.5
Fused alumina	Short ton	56.04[g]	3,143	*5.6*	*11.2*	*14.0*	16.8	19.6	22.4	28.0	33.7	39.3	44.9	50.5	56.1	0.35
Silicon carbide	Short ton	72.93[g]	9,380	*12.9*	25.7	32.2	38.6	45.0	51.4	64.3	77.2	90.0	102.9	115.8	128.6	0.35
Calcium carbide	Short ton	100.00	3,150	*3.2*	*6.3*	*7.9*	*9.4*	*11.0*	*12.6*	15.8	18.9	22.0	25.2	28.4	31.5	0.35
Allied:																
Anhydrous ammonia	Short ton	90.00	1,530	1.7	3.4	4.2	*5.1*	*6.0*	*6.8*	*8.5*	*10.2*	*11.9*	*13.6*	15.3	17.0	0.3-0.5

a. Represents manufacturers' prices as of January 3, 1938, from prices published by *Oil Paint and Drug Reporter*, *Engineering and Mining Journal*, and *Industrial and Engineering Chemistry*, except as noted.

b. Represents all energy directly chargeable to each product for the operation specified, including electrolytic, electrothermal, motor, lighting, and incidental loads.

c. Representative data are not available.

d. Represents energy directly chargeable to process only.

e. Based on a price of 15.5 cents per pound for metallic sodium and 2.15 cents per pound for chlorine.

f. Based on a price of 2.7 cents per pound for caustic soda (76 per cent solid) and 2.15 cents per pound for chlorine.

g. Average value of United States and Canadian production of crude material during 1936, from data published by the United States Bureau of Mines

their requirements for electric energy and their contribution to the resources of modern civilization.

Probable Resultant Trends

Past experience and the present outlook indicate that the total electric requirements of this particular group of industries will expand at a rate somewhat greater than that of general industrial activity, because requirements for the products themselves are clearly increasing at rates higher than the average.

Added to this underlying tendency will be the potentially much larger incremental use of electric energy where changing conditions make the electroprocesses more advantageous or less costly than older methods, as well as perhaps equally great increments obtained from new products and processes now in various stages of development. Such compounding of growth factors should be recognized in providing for the national power requirements of the near future, particularly in regions where the availability of raw materials and low-cost electric power are favorable to these developments.

On the north Pacific coast large and immediate possibilities of low-cost hydroelectric energy suggest the definite possibility of aluminum reduction from foreign ores to be delivered by cargo shipment on the Columbia River or on Puget Sound. The availability of iron ore, of iron and steel scrap, and of coking coal suitable for electric furnace production, and the relatively small local capacity now installed, indicate that the electric production of iron and steel alloys may be commercially feasible in the near future.

Widespread deposits of manganese, chromium, and other ores strengthen the possibility of ferroalloy production. Extensive resources of phosphate rock in Idaho, Wyoming, Utah, and Montana are available for the manufacture of phosphoric acid and phosphates.[3] More immediate prospects for the development of sodium chlorate and of calcium carbide are also to be noted.

In the southwestern states, ferroalloys and especially ferromanganese offer distinct possibilities. Zinc deposits near Pioche, Nev., are favorable for either electrolytic or electrothermal production of zinc and zinc oxides. Magnesites in California and alunites in Utah may be used for production of electrolytic magnesium and electric-furnace potash.[3] The ability to make potassium nitrate from potassium chloride and nitrogen peroxide (derived from ammonia), together with the potential need for additional ammonia for fertilizer use, indicate that new capacity for synthetic ammonia may be expected; perhaps utilizing power from Boulder Dam.

In the southeast, the greatly increased production of paper and pulp from enormous regional resources of timber foreshadows a future need for power in these operations and also in the production of chlorine and caustic soda for process purposes. Electric furnace

Table VI. Consumption of Electric Energy per Year

Product	Past Requirements[a] (Kilowatt-Hours)	Future Requirements Probable Within Five Years (Kilowatt-Hours)	Ratio to Past Requirements (Per Cent)
Aluminum	2,597,000,000	3,600,000,000	139
Copper	2,600,000,000	2,500,000,000	96
Zinc (electrolytic)	515,000,000	850,000,000	165
Magnesium	39,000,000	100,000,000	256
Chlorine and caustic soda (electrolytic)	1,568,000,000	1,900,000,000	121
Electric furnace iron	105,000,000	200,000,000	190
Electric furnace steel	743,000,000	1,100,000,000	148
Electric furnace ferroalloys	1,752,000,000	2,500,000,000	143
Heat-treating	2,200,000,000	3,000,000,000	136
Artificial abrasives	87,000,000	116,000,000	133
Calcium carbide	550,000,000	1,100,000,000	200
Carbon and graphitized products	196,000,000	300,000,000	153
Nitrogen	288,000,000	375,000,000	130
Potash	84,000,000	140,000,000	167
Total	13,324,000,000[a]	17,781,000,000	133

a. Year 1936; except for copper, where 1929 is used because it is the only year for which complete data on power consumed in mining, milling, smelting, and refining of copper are available. For this reason and also because energy requirements for cadmium, brass, and inorganic fertilizers are not included, the total shown cannot be reconciled with the figure of 12,500,000,000 kilowatt-hours given for 1936.

production of phosphoric acid and phosphates has begun near Sheffield, Ala., Anniston, Ala., and Nichols, Fla.

Increased production of ferroalloys and of calcium carbide is presaged by the announced construction of new capacity[2] and by the availability of raw materials, local markets, and low-cost power. The many deposits of dolomite in the Tennessee Valley suggest the possibility of developing a local magnesium industry when domestic demands exceed the existing capacity at Midland, Mich.[3]

Estimates of future power requirements affecting the electroprocessing industries are based on past growth, on probable changes in the markets for the materials in their older uses, on new uses and new processes that are known to be of prospective importance, and on the continued availability of low-cost electric energy in certain regions.[3]

Extraordinary influences, such as a war or a major change in the business cycle, have been excluded from consideration as being impossible to evaluate usefully either in magnitude or in time of occurrence. The high level recorded in the first nine months of 1937 has been discounted, together with the sharp curtailment of power consumption which began in the last quarter of the same year.

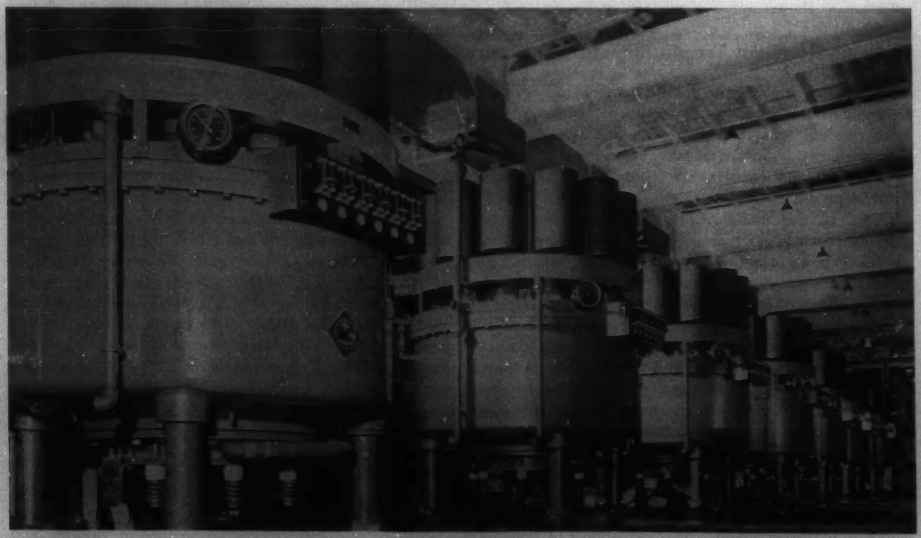
The problem of estimating these future power requirements is not to establish whether they will occur, but rather to indicate their approach sufficiently far in advance to permit the orderly development of power resources to meet the increased needs. A summary of these estimates, compared with the recorded actual consumption, is presented in table VI.

References

1. Monthly and Annual Production of Electricity for Public Use, Federal Power Commission, April 12, 1937, page 1.

2. Economies Resulting From Improved Regulation, J. V. Alfriend, Jr., *Chemical and Metallurgical Engineering*, April 1932, pages 209–11.

3. Power Requirements in Electrochemical, Electrometallurgical, and Allied Industries, Federal Power Commission, 1938.



These mercury-arc rectifiers at the Alcoa, Tenn., plant of the Aluminum Company of America have 55,000-kw capacity

Treasure Island Awaits Summer Conventioners

THE combined AIEE summer and Pacific Coast convention, which will be held in San Francisco, Calif., June 26–30, 1939, offers members and guests unusual opportunities to combine business and pleasure. The technical program will include outstanding papers on a variety of pertinent subjects, round-table conferences, student meetings, and related activities. Entertainment will feature the Golden Gate International Exposition, which has designated Tuesday, June 27, as AIEE Day. Sports and entertainment have been arranged and extensive plans have been made to entertain the women guests.

The Golden Gate International Exposition, located on man-made Treasure Island in the middle of San Francisco Bay, is easily accessible by auto, taxi, or ferry; compactly designed, all of its many features are within easy walking distance of each other. Old masters, including priceless works loaned by the Italian Government, and modern painting feature an exceptional exhibit of art. Fluorescent-tube lighting is employed extensively. Exterior floodlighting of buildings, trees, shrubs, and flowers is particularly good. The total electrical load is equal to the demands of a city of 50,000.

Immediate Hotel Reservations Necessary

Convention headquarters will be at the Fairmont Hotel, which overlooks San Francisco Bay and Treasure Island. Since hotel accommodations in the city are expected to be in great demand because of the exposition, members are urged to make early reservations. It is extremely important that reservations, if not already made, be made immediately. The rates for the Fairmont, as well as for several other principal hotels in San Francisco, were given in a preliminary announcement of the convention in the April issue, page 177.

San Francisco and its environs provide many scenic attractions for those traveling to and from the convention. The bay area, California, and the entire Pacific Coast abound with natural attractions of wide variety. Near San Francisco are Muir Woods, Mount Tamalpais, and the ocean beaches. Within an easy one-day drive are Varmel, Monterey, Del Monte, Santa Cruz, and Big Basin. Slightly farther away are the Redwood Empire, Yosemite National Park, Lassen Park, General Grant and Sequoia Parks, and Lake Tahoe. In Southern California the many beaches, the movie studios, and other attractions lure many tourists. Oregon, Washington, and British Columbia likewise contain many points of interest. Visitors from east of the Rockies may well include Grand Canyon, Boulder Dam, Grand Coulee, Glacier Park, or Yellowstone Park in their itineraries. Those who prefer to motor will find the highways to California numerous and in good condition. For those traveling from New England and the Atlantic Seaboard region special accommodations with connections at Chicago, Ill., and St. Louis, Mo., offered by the New York Central System were described in the April issue, page 177.

Technical Sessions

The program will comprise nine or ten technical sessions, four or five round-table discussions, and student technical sessions. With a view toward including as many papers as possible on some of the latest technical developments details of the technical program could not be included in this announcement, but will be given in the June issue. Subjects that will form the basis for sessions arranged so far are as follows: protective devices, communication, instruments and measurements, electrical machinery, power transmission and distribution, industrial power applications, electronics, basic sciences, research, automatic stations, lighting, and transportation.

Entertainment

For the purpose of getting acquainted, an informal reception and tea for members and their guests will be held Monday afternoon, June 26, at five o'clock at the Hotel Mark Hopkins, directly across the street from the Fairmont Hotel. Tickets are free but must be secured at the registration desk by two o'clock Monday to permit the hotel to make proper arrangements.

As previously stated, Tuesday is AIEE Day on Treasure Island. To allow everyone an opportunity to visit the exposition that day, no technical papers or conferences are scheduled for Tuesday afternoon. In the evening, there will be an informal dinner in the ballroom of the California State Building. Tickets will be two dollars per plate and must be obtained at the registration desk, Fairmont Hotel, not later than eight o'clock Monday evening.

The convention banquet with entertain-

Tentative Schedule of Events

All Sessions and Conferences Will Be Held at the Fairmont Hotel

Monday, June 26

8:30 a.m.—Registration (desk open Sunday—2:00 to 8:30 p.m.)

10:00 a.m.—Annual Meeting
Reports, presentation of prizes for papers, presentation of Lamme Medal, and president's address

Afternoon —Sports

2:00 p.m.—Conference of officers, delegates, and members
San Francisco bus trip for ladies

5:00 p.m.—Informal reception and tea for men and women, Mark Hopkins Hotel

Tuesday, June 27

9:00 a.m.—Three parallel technical sessions

Afternoon —Sports
AIEE Day at Golden Gate International Exposition, Treasure Island

6:00 p.m.—Treasure Island—dinner (informal) in ballroom, California State Building

Wednesday, June 28

9:00 a.m.—General session

Afternoon —Sports

2:00 p.m.—Conference of officers, delegates, and members
Two or three round-table discussions
Student technical sessions

7:00 p.m.—Student Branch dinner, followed by joint conference of Student delegates and counselors of Districts 8 and 9

Thursday, June 29

9:00 a.m.—Three parallel technical sessions

11:30 a.m.—Peninsula bus trip and tea for women (return by 5:30 p.m.)

Afternoon —Sports

2:00 p.m.—Student technical sessions
Two or three round-table discussions
Bridge at hotel (alternative)

7:00 p.m.—Convention banquet (awarding of sports' prizes)—Hotel Fairmont

9:00 p.m.—Dancing

Friday, June 30

9:00 a.m.—Three parallel technical sessions

Afternoon —Inspection trips

ment and dancing will be held at the Fairmont Hotel, Thursday evening, at seven. The sports' prizes will be presented, and all members and guests are urged to attend this closing entertainment feature of the convention.

Women's Entertainment

On Monday at two o'clock busses will leave the Fairmont Hotel on a trip to outstanding points of interest around San Francisco. This trip will follow to a large extent the celebrated "45-mile scenic drive" and will take about two hours. Men are invited. Tickets will be free for out-of-town members and guests, and one dollar each for residents of the bay area. All tickets must be obtained in advance at the registration desk.

A trip for women through San Mateo County has been arranged for Thursday; the party will leave the Fairmont Hotel at 11:30 a.m. Luncheon will be served in Palo Alto at the Allied Arts, which is noted for its handicraft arts, its fine cuisine, and beautiful surroundings. After lunch, the Stanford University grounds will be visited, and the return to San Francisco will be through the many attractive suburban communities which dot the peninsula. Tickets must be obtained at the Fairmont Hotel by eight o'clock Wednesday evening.

Sports

Excellent facilities for golf and tennis abound in San Francisco and the bay area. Swimming also may be enjoyed in the Fairmont pool. Golden Gate Park contains many miles of bridle trails.

The qualifying round, 18 holes, for the Mershon golf trophy and the first 18 holes of medal play for the Lee trophy will be played at the Claremont Country Club in Oakland, Monday afternoon. The last 18 holes for the Lee trophy, and the John B. Fisken cup competition, which is open only to members of AIEE Districts 8 and 9, will be played on this course Thursday afternoon. Play at other times and on other courses may be arranged by request to members of the sports committee.

The Mershon tennis tournament for men, and other matches for both men and women, will be played at the California Tennis Club in San Francisco. Play will commence Monday afternoon.

Inspection Trips

Stanford University. A half-day trip to this institution will include a special demonstration at the Ryan High-Voltage Laboratory.

University of California. A trip across the San Francisco Bay Bridge to the university campus will include a visit to the recently completed cyclotron.

Station "A," San Francisco. Largest steam plant of the Pacific Gas and Electric Company, with two 50,000-kw turbines operating at a steam pressure of 1,400 pounds per square inch.

Sterling Substation. Located at the San Francisco terminus of the Bay Bridge, this station contains 600-volt and 1,300-volt rectifiers supplying the two interurban railway systems using third rail and trolley. The train control and signal system across the bridge, one of the busiest of double-track interurban railways, also may be inspected.

Newark Substation. This station is the terminus of 2 220-kv, 16 110-kv, and 3 60-kv lines, with 227,500-kva transformer and 75,000-kva synchronous condenser capacity.

Registration

Members who will attend the convention should register in advance by filling in and mailing the advance registration card received with the mailed announcement. This will assist the committees in making advance arrangements and minimizing congestion at the registration desk upon arrival. A registration fee of three dollars will be charged all nonmembers except Enrolled Students and the immediate families of members.

Convention Committee

The personnel of the 1939 summer and Pacific Coast Convention committee is as follows: S. J. Lisberger, *general chairman;* D. I. Cone, *vice-chairman;* G. C. Tenney, *secretary;* R. O. Brosemer, *treasurer;* F. S. Benson, A. M. Bohnert, C. F. Bowman, C. B. Carpenter, O. B. Coldwell, P. M. Downing, C. E. Fleager, L. F. Fuller, L. R. Gamble, David Hall, N. B. Hinson, J. P. Jollyman, R. E. Kistler, H. J. MacLeod, J. A. McDonald, P. J. Ost, G. E., Quinan, C. E. Rogers, E. F. Scattergood, R. W. Sorensen, H. A. Stingle, and F. E. Terman. Subcommittee chairmen: M. S. Barnes, *registration;* R. J. Cobban, *sports;* E. A. Crellin, *hotel;* H. W. Flye, *entertainment and reception;* F. R. George, *trips and local transportation;* J. S. Moulton, *publicity;* Stanley Rapp, *transportation;* H. H. Skilling, *student activities;* W. C. Smith, *program;* and Mrs. S. J. Lisberger, *women's entertainment.*

Notice of Annual Meeting

The annual meeting of the American Institute of Electrical Engineers will be held at the Fairmont Hotel, San Francisco, Calif., at 10 a.m. on Monday, June 26, 1939. This will constitute one session of the summer and Pacific Coast convention which is to be held this year in that city.

At this meeting, the annual report of the board of directors, and the report of the committee of tellers on the ballots cast for the election of officers will be presented.

Such other business, if any, as properly may come before the annual meeting may be considered.

(Signed) H. H. Henline
National Secretary

New Book on Power Transmission. "Electrical Transmission and Distribution of Power" has recently been published by Dean H. V. Carpenter (A'03, F'18) of the State College of Washington, Pullman. Written to serve a triple purpose—senior text, guide to related periodical and other technical literature, useful reference book for an engineering office—this book has been published by the lithoprint process, contains 100 8½- by 11-inch pages, and is multiring bound to enable it to open flat as a convenience of use. It has been announced as available at $2.00 per copy postpaid from the Student Book Store, Pullman, Wash.

Summer Convention Attenders May See—

(1) The 1939 Golden Gate International Exposition. On Treasure Island, man-made site of the exposition in San Francisco Bay, the towers, courts, and palaces of the grounds are here seen from nearby Yerba Buena Island

(2) Exposition exhibits of particular interest to AIEE members. The fluted building of the Westinghouse Electric and Manufacturing Company, in the Palace of Electricity and Communications, contains X-ray apparatus, single-stage geared turbine demonstrator, electrical porcelain, household appliances, "Elektro" the automaton, and other displays

(3) The magnificent scenery of the western United States. Here shown is El Capitan cliff, rising sheer for 3,600 feet in Yosemite National Park, Calif. Besides scenic features of California, conventioners may make the trip include the Grand Canyon, Yellowstone Park, or the Canadian Rockies (Southern Pacific photo)

(4) Interesting industrial plants. Illustrated is the oil-circuit-breaker assembly floor at the Pacific Electric Manufacturing Company, San Francisco, Calif.

(5) More Golden Gate Exposition exhibits. The General Electric Company features half-hour stage shows in its House of Magic; also offers for inspection an international broadcasting station, a "magic kitchen," which moves and talks, and a glass blower making replicas of Edison's first incandescent lamp

(6) The unique "Pacific" architecture of the exposition. Pylons adjoining the palaces on the Court of the Seven Seas are crowned with galleon prows ornamented with sculptured figureheads

(7) The only Chinese telephone office outside China. The Chinatown exchange of the Pacific Telephone and Telegraph Company, San Francisco, Calif., occupies a building of Chinese design, with triple pagodas to indicate its importance

(8) Power equipment. Shown here is Station "C," of the Pacific Gas and Electric Company, Oakland, Calif. The plant was recently enlarged to a total generating capacity of 155,999 horsepower; the first unit, built in 1908, had a capacity of only 12,000 horsepower

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Progress Reported in Conference on Sound Measurement

THE conference on sound measurement held during the AIEE 1939 winter convention, under sponsorship of the subcommittee on sound of the AIEE standards committee, attracted widespread interest; the discussion was participated in by some 20 speakers, and the total attendance was well over 100. This summary report of the conference was prepared by P. L. Alger, chairman of the subcommittee.

Marked progress in the accuracy and uniformity of sound measurement was reported, numerous recent comparisons of sound-level meters of different makes at the Bureau of Standards and elsewhere having shown agreement to the order of one decibel, as contrasted with a seven-decibel range of discrepancy noted a year ago.

R. G. McCurdy (A'16, F'34) reported on conferences held with experts abroad, on his recent trip to Europe. French, German, and English authorities are now generally agreed on the use of objective noise meters, similar to the American standard type, for all usual noise measurements, but there is still a considerable difference of opinion on the most desirable dynamic characteristics of the meter, and on the exact relations between the true loudness of a complex noise and the meter reading itself. The International Committee on Acoustics delayed action on the adoption of sound-level-meter standards for international use because of this difference of opinion. The International Committee on Telephony (CCIF) however, has tentatively adopted the American sound-level-meter standard for the measurement of room noises.

Standard American meters have a time of response of 0.2 to 0.25 second, which results in some averaging effect on rapidly varying noises. There is a considerable volume of opinion, which desires a shorter time of response, or some form of peak-noise-reading meter, to read more nearly the maximum than the average sound level of such noises as produced by a riveting hammer or by the exhaust of a gasoline engine. Mr. McCurdy stated, however, that none of the information or opinions noted abroad warranted, in his opinion, any present change in the American sound-level-meter standards.

General opinion both here and abroad is that the true loudness of a complex noise, as judged by a large number of observers, increases somewhat more rapidly with the sound energy level than is indicated by the standard objective type of sound-level meter. The term "phon" has been adopted internationally as the name for this psychological sound level, as judged by the average observer, and several investigators have proposed approximate calibration curves to correct the decibel reading of a sound-level meter to the equivalent "phon" value. The values obtained by different observers vary considerably, however, and the magnitudes of the corrections to the objective meter readings have not been well enough established to warrant their use at present.

V. L. Chrisler reported on the work of the Bureau of Standards in developing basic reference standards and calibration methods. He said that comparisons of several commercially available types of meters and microphones, including the new ribbon microphone design, have shown agreement within one-half decibel, except for the obstacle effect present when large microphones are used. The Bureau is now willing to calibrate microphones and sound-level meters as a routine test for an appropriate fee. He also reported that various governmental authorities are now requiring noise guarantees to be met in the purchase of fans and other apparatus, so that the Bureau is especially interested in the development of more precise commercial test codes for noise measurement.

J. M. Barstow described work done by the Bell Telephone Laboratories with an "acoustical calibrator," or standard reference noise, which was exhibited at the meeting of the Acoustical Society of America in Washington, D. C., last summer. Discussion indicated that there is an important need for a standard reference source of a complex noise of this type for use in field calibration of meters, and it was agreed that the committee should give further study to this subject.

G. T. Stanton suggested that a second type of objective sound-level meter should be developed, especially for use in commercial measurements of apparatus noise, where one or two definite frequencies compose a major part of the sound energy. He pointed out that the tolerance of five decibels or more in the frequency response permitted by present American standards is so large that comparisons of measurements made at different places and with different meters are not sufficiently accurate for some purposes. Paul Huber supported this proposal, and stated that a large automotive organization maintains ten sound-level meters in field service continuously, comparing noise levels produced by automobile engines and similar equipment in different locations and with different lengths of service. Discussion indicated, however, that the tolerance permitted by the standards is required to cover variations in the response of individual microphones to particular frequencies, and that the actual tolerance between complex noise readings, which cover a range of frequencies, is much closer than the standards would indicate. Furthermore, if a meter is calibrated with a particular microphone, corrections can be made which will enable an accuracy of one or two decibels in comparisons to be obtained. It was concluded, therefore, that the present need is to develop more convenient and accurate calibration methods, rather than to modify the standards. The committee, however, decided to review the American standards in this respect and suggest any reductions in tolerances or other alterations that seem desirable.

D. F. Seacord (A'18) presented a report on the sound levels existing in offices, factories, and residences, compiled from measurements in 900 different locations. Besides giving average sound levels in these different locations, he showed the range of variation existing, the numerical values being approximately as follows:

For the typical residence, the sound-level averages approximately 40 decibels, 95 per cent of the observed values lying within a range of 30 to 50 decibels.

For large business offices, the average level is about 57 decibels, 95 per cent of the values lying between about 38 and 75 decibels.

For factories, the average level is about 77 decibels, with a range from 60 to 95 decibels.

All these readings were taken at locations adjacent to a telephone, the purpose in view being to obtain information to be used as a basis for working out methods for more accurately reflecting the effects of room noise in the design of the telephone plant.

W. Mikelson presented a report on the AIEE Test Code for Apparatus Noise Measurement, which was published in preliminary form in the September 1937 issue of ELECTRICAL ENGINEERING. Since that time a number of suggestions have been received concerning it, and experience also has indicated the desirability of minor changes. On this basis, several changes in the code were agreed upon, and subsequently the subcommittee voted to transmit the amended code to the standards committee with recommendation for printing by the Institute.

The 3 principal changes were the permissive use of maximum instead of average sound-level readings, in the case of some small apparatus types with highly directional noise characteristics; a more complete statement in regard to the method of averaging sound-level readings; and the inclusion of information in regard to the apparent loudness of a sound in comparison with its decibel value indicated by a meter.

Anthony Pinto (A'11, M'18) presented information on the work of several committees of the National Electrical Manufacturers Association that are drafting specific test codes for measurement of apparatus noise, particularly fans, small motors, and transformers. The NEMA Transformer Code has recently been approved, and the fan and motor codes are now in draft form, so that requests for quiet apparatus can be handled on a satisfactory commercial basis. In general, these specific test codes require the averaging of sound-level measurements taken at points 45 degrees apart along a line encircling the apparatus at a distance of one foot for motors and transformers, and three feet for fans. These NEMA codes are so drawn as to be in accord with the basic values in the AIEE Test Code. Discussion at the meeting stressed the desirability of having all apparatus test codes to be developed by the different commercial organizations similarly agree with the basic AIEE Test Code, to avoid confusion and permit the most accurate comparisons. The value of these conferences, in developing the co-operation necessary to secure this basic uniformity between test codes was strongly pointed out by several speakers.

The final speaker at the conference was A. P. Fugill (A'24, M'30) who presented a report on the experience of The Detroit Edison Company in purchasing transformers under a noise specification. This specification was presented in preliminary form at the 1938 conference. Mr. Fugill stated that a number of careful comparisons of the sound level of particular transformers,

measured first at the factory both by the manufacturer and by The Detroit Edison Company representative using his own meter, and then by The Detroit Edison Company at the company's warehouse, have shown a difference in every case of less than two decibels, with an average error of materially less than one decibel. As a result of extensive observations on transformers under warehouse and field conditions, a curve of satisfactory sound levels versus transformer capacity has been established, and all transformers purchased by the company are now required to come within these values.

AIEE 17-Year Index Now Completed

The fourth in the series of published indexes to technical papers and discussions published in the AIEE TRANSACTIONS is now off the press and ready for distribution. Covering the years 1922–38, inclusive, the volume contains 160 pages and its over-all dimensions and type of binding are similar to those of recent TRANSACTIONS volumes.

In preparing the index, maximum serviceability to its users is the factor that has been given the greatest consideration. The titles of all technical papers published during the 17-year period are liberally cross-referenced in section 1, which comprises the subject index. In section 2, the author index, are listed the names of all authors and co-authors of all papers and discussions published during that period.

TWO INDEXES FOR THE PRICE OF ONE

The new index volume is nominally priced at $2.00 per copy, postpaid; $3.00 to non-members, with the usual discounts to college and public libraries. As an added inducement, a copy of the last preceding index volume, covering papers and discussions published during the years 1911–21, will be included free of charge with every copy of the new index.

Those who already have ordered copies of the new index, in response to previous announcements, will receive their copies within a short time. Those who have not already ordered and wish to do so now may find a convenient order form on page 1, advertising section, this issue. Since the edition is limited, it is important that orders be placed promptly.

NEMA Conference With Department of Commerce

A series of meetings presenting services of the United States Department of Commerce available to all electrical manufacturers was held March 30 and 31, 1939, at the Department of Commerce Building, Washington, D. C., under the auspices of the National Electrical Manufacturers' Association.

Harry L. Hopkins, Secretary of Commerce, greeted the delegates at the opening session. Speakers from various bureaus of the Department discussed the services available and their special application to electrical manufacturing in four conference sessions.

The first session dealt with domestic commerce services of the Bureau of Foreign and Domestic Commerce; the second with services of the Census Bureau; the third included activities of the Patent Office, National Bureau of Standards, and the Trade Agreements Unit of the Bureau of Foreign and Domestic Commerce; and the final session was concerned with foreign commerce services of the Bureau of Foreign and Domestic Commerce.

At the dinner meeting on March 30 the speakers were Dr. Willard L. Thorp, special economic advisor to the Secretary of Commerce, on "The National Economic Survey," and Richard C. Patterson, Jr., Assistant Secretary of Commerce, on "What are the Prospects for Business." Carl L. Peirce, Jr., president, NEMA, presided at the dinner.

AIEE Yale Branch Honors Doctor Scott

AIEE Student Branch recognition of the approaching 75th birthday of Doctor C. F. Scott (A'92, F'25, HM'29) began with a dinner and meeting given in Doctor Scott's honor by the Yale University Branch, New Haven, Conn., March 17, 1939. Doctor Scott, who inaugurated Student Branches during his presidency of the AIEE 1902–03, was head of the department of electrical engineering at Yale for 22 years, and himself founded the Yale Branch. Yale therefore arranged to be the first of the Student Branches to commemorate the "diamond jubilee" of their founder, acting upon the suggestion made last year by R. W. Sorensen, chairman, committee on Student Branches.

Photos by J. L. Daley

Doctor C. F. Scott receives from J. G. Stephenson, chairman, AIEE Yale Student Branch, the commemorative plaque shown here, expressing student appreciation of his attainments

The celebration at New Haven began with a banquet at the Yale Faculty Club, followed by a meeting of students and faculty members, at which Doctor Scott spoke on the development of electric power at Niagara Falls, the invention of the two-phase—three-phase Scott connection, and other matters of engineering history. He was introduced by Branch Chairman J. G. Stephenson, whose tribute was partly in verse form, and both introduction and address were interrupted at strategic intervals by humorous songs by a trio of students. At the conclusion of his speech, Doctor Scott was presented with a complimentary plaque as a symbol of student appreciation of his achievements. The meeting, which ended with an informal reception, was reported by J. G. Stephenson, Branch chairman, and A. E. Were, Branch secretary. The songs and other verses for the occasion were written by Professor A. G. Conrad (A'27) of the electrical-engineering department.

Future AIEE Meetings

North Eastern District Meeting
Springfield, Mass., May 3–5, 1939

Summer and Pacific Coast Convention (combined)
San Francisco, Calif., June 26–30, 1939

Great Lakes District Meeting
Minneapolis, Minn., September 27–29, 1939

Middle Eastern District Meeting
Scranton, Pa., October 11–13, 1939

Winter Convention
New York, N. Y., January 22–26, 1940

1939 AIEE Year Book Is Now Available

In accordance with the provisions of the Institute's 1938–39 budget as approved by the finance committee and the board of directors, the 1939 edition of the AIEE Year Book has been issued, in limited edition, and is available to members of the Institute who have use for it. The book contains essentially the same material as was included in the 1938 edition; business and mailing addresses have been corrected as of February 28, 1939.

In keeping with established custom, copies of the Year Book have been distributed to all national, District, and Section officers, to Student Branch counselors, and to all members of all national committees. Other members wishing to secure a copy may do so by writing to the AIEE order department, 33 West 39th Street,

New York, N. Y., giving correct mailing addresses.

The Year Book is not available to nonmembers of the Institute, nor is its use permitted for commercial, promotional, or other circularization purposes.

Engineers' Day at San Francisco Fair. Designated as Engineers' Day, Wednesday, July 13, 1939 at the Golden Gate International Exposition in San Francisco, Calif., will commemorate the engineer's contribution to human welfare. The celebration, which is sponsored by the San Francisco Engineering Council, will include inspection of the outstanding engineering and industrial exhibits at the exposition. National conventions of several engineering and scientific societies are being held in San Francisco near the date chosen to honor engineering achievement.

New Index to ASTM Standards. The American Society for Testing Materials has issued a new Index to ASTM Standards and Tentative Standards, covering the 870 standards existing as of January 1, 1939. The Index, a 140-page booklet, six by nine inches in size, may be obtained without charge from ASTM headquarters, 260 South Broad Street, Philadelphia, Pa.

AIEE Mansfield Division Becomes 67th Section

The Mansfield (Ohio) division of the AIEE Cleveland Section which was formed in December 1938 (*EE, Jan. '39, p. 39–40*) has become the Mansfield Section, by recent action of the Institute's executive committee and committee on Sections. The 67th Section of the Institute includes in its territory Marion, Morrow, and Knox counties, Ohio, formerly in the Columbus Section; Crawford County, formerly in the Toledo Section; Richland County, formerly in the Cleveland Section; and Ashland County, formerly in the Akron Section. Transfer of these areas was authorized by the various Sections.

Members and applicants in the new Section now number 71. The officers are: chairman, C. A. Faust (A'35), advertising department, Ohio Brass Company, Mansfield; vice-chairman, H. F. Herbig (A'23), research engineer, North Electric Manufacturing Company, Galion; chairman of attendance and publicity, W. A. Barnes (A'24), chief engineer, Dominion Electrical Manufacturing Company, Mansfield; and secretary-treasurer, F. H. Milliken (A'33), design engineer, Ideal Electric and Manufacturing Company, Mansfield.

Officers of the newly organized AIEE Mansfield Section: left to right, Messrs. Barnes, Herbig, Faust, Milliken

Standards

Co-ordinating Committees on Standardization Activities

With each technical committee of the Institute carrying on its standardization work more or less independently of the others, certain unnecessary differences in various practices, such as the use of reference values, have crept in, detracting from the desired simplicity of the entire standards structure and resulting in confusion and misunderstanding. The standards committee, realizing this situation, felt that it should take what steps it could to bring about greater co-ordination of these standardization activities. It is realized, of course, that some of the subjects requiring co-ordination are under consideration by agencies outside of the Institute, and therefore every effort will be made to have the Institute committees cooperate with these agencies.

A survey of the standards activities has further brought out that there is standards work relating to broader subjects than those ordinarily falling within the scope of the existing technical committees which the Institute might carry on, or at least initiate to good advantage.

The standards committee has therefore decided to set up a number of co-ordinating committees for the following purposes:

(*a*). To compile data on existing conditions and standards which will assist in the co-ordination of standards avoiding duplications and inconsistencies.

(*b*). To prepare guiding principles to be used by other AIEE committees in their standards work.

(*c*). To maintain contact with all interested AIEE committees and assist in the co-ordination of AIEE standards with other national and international standards activities.

(*d*). To recommend, initiate, or sponsor through the standards committee setups in the ASA, IEC, and other standardization bodies which seem desirable or expedient for bringing about maximum co-ordination of standards in the electrical field.

(*e*). To initiate, in co-operation with interested AIEE technical committees, regular or informal Institute sessions for the purpose of discussing standardization matters.

In the activities of these co-ordinating committees or their subcommittees, care will be taken that the interested technical committees are represented either by their chairmen or by members designated by them.

The following four co-ordinating committees have already been organized, with chairmen as indicated:

1. Reference values for standards, J. F. Meyer, chairman.

2. Standard voltages and currents, C. A. Powel, chairman.

3. Insulation testing and co-ordination, C. A. Powel.

4. Basic principles for rating of electrical machines and apparatus, P. L. Alger, chairman.

The chairmen of these committees will report in detail on their plans and contemplated activities in future issues of ELECTRICAL ENGINEERING.

The standards committee feels that the membership in general should be informed regularly of any important standards activities of the Institute, and therefore a subcommittee on publicity, with P. L. Alger as chairman, has been appointed to report regularly in ELECTRICAL ENGINEERING any items of interest.

Co-ordinating Committee on Basic Principles for Rating

The standards committee has appointed AIEE co-ordinating committee 4 on basic principles for rating of electrical machinery and apparatus, to consider the information presented at the symposium on rating, held during the 1939 winter convention, and to review AIEE Standards No. 1, "General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery and Apparatus." The following brief statement of objectives of this committee has been prepared by P. L. Alger, chairman, for the information of Institute members and others interested. Specific recommendations or information that may be helpful to the committee should be sent directly to the secretary E. B. Paxton.

The committee as organized consists of a small working committee and a large advisory committee, including representatives from all of the AIEE technical committees and other Institute members especially interested in rating problems. In order to keep the Institute membership informed of progress in this work and to obtain additional information bearing on the subject, it is proposed to have one or more papers and discussion sponsored by the committee at both the combined summer and Pacific Coast convention, San Francisco, Calif., June 26–30, 1939, and the Middle Eastern District meeting, Scranton, Pa., Oct. 11–13, 1939. At the summer convention, a paper will be given on ambient temperatures and weather conditions affecting the operation of electrical apparatus, and it is hoped that discussion will make available new information on weather conditions and temperatures characteristic of the western part of the country. At the Middle Eastern District meeting it is hoped to have papers dealing with the operating conditions met with in industry, and giving further information on the methods of testing and rating electrical machines.

The immediate objective of the committee is to review, and to modify where de-

sirable, the general principles on which temperature limits are based in rating electrical apparatus, so as to assure a continuing sound basis for the further development of the American system of electrical-apparatus rating.

Under this broad objective, the following specific proposals are suggested for consideration:

1. Determine whether recent investigations, service experience, or the trend of international standardization warrant any changes in the temperature limits of classes of insulation now covered.

2. Consider recent developments of new or improved insulating materials, and determine what changes, if any, should be made in AIEE Standards No. 1 to recognize adequately and limit properly the application of different insulations.

3. Review present practices and trends as to methods of temperature determination, and the conventional allowances associated with such methods; and, if desirable, make new provisions to accord with the modern trend to protected and enclosed types of apparatus.

4. Consider what fundamental provisions in the standards, if any, may be desirable, because of the more exacting methods of utilizing the inherent capacity of apparatus under various conditions of service, as now recognized in the AIEE Guide for Operation of Transformers.

The long-range objective is to establish a committee including experts familiar with rating problems in all types of apparatus, that will continuously maintain a watch over the principles of rating employed in the standards for the various types of apparatus, and will take whatever steps may be necessary to preserve proper co-ordination between these standards. While the question of temperature limits and methods of temperature measurement are of the first importance in this connection, as indicated, questions of standard units and nomenclature for measurement or description of torque, power, and other apparatus characteristics require consideration; and a broad plan for correlating the short-time or intermittent ratings of associated apparatus used in the same service is desirable.

For example, whatever temperature standards are adopted for rotating apparatus, they should be consistent with the ratings of control, wiring, fuses, and other associated equipment. It is proposed, therefore, that this committee deal with basic principles appearing in more than one standard, which have to do with questions of temperature and other factors involved in the output rating of apparatus. This does not include, however, questions of standard voltages, or insulation co-ordination, which will be handled by separate committees.

Current Items From American Engineering Council

Civil Service Seeks Advice From Profession

The President's Committee on Civil Service Improvement has authorized the appointment of a number of special advisory committees and Gano Dunn (A'91, F'12) a member of the President's Committee, with the assistance of officers of the National Academy of Sciences, the National Research Council and others, the American Engineering Council, the American Society of Civil Engineers and other leading engineering and technical societies, has appointed three such committees of five members each—one, covering the fields of mathematical, physical, and biological sciences, called for short, the science committee; a second, covering the fields of the general engineering societies consisting of the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, the American Institute of Electrical Engineers, the Institute of Radio Engineers, which is known as the general engineering committee; and a third committee covering the fields of the specialized engineering societies, consisting in part of the American Society of Heating and Ventilating Engineers, the Society of Automotive Engineers, the American Society of Agricultural Engineers, the Illuminating Engineering Society, the American Society of Refrigerating Engineers and representatives of local and state engineering societies, to be known as the specialized engineering committee. The members of these three committees are as follows:

Science Committee

R. G. HARRISON, *chairman*, chairman, National Research Council, care Yale University, New Haven, Conn.

J. A. FLEMING, director, dept. of terrestrial magnetism, geophysical laboratory, Carnegie Institution of Washington, Washington, D. C.

L. J. BRIGGS, director, Bureau of Standards, Washington, D. C.

W. C. MENDENHALL, director, Geological Survey, Washington, D. C.

ROGER ADAMS, professor, organic chemistry, University of Illinois, Urbana.

General Engineering Committee

E. P. GOODRICH, *chairman*, consulting engineer, chairman, committee on salaries, ASCE, 175 Fifth Avenue, New York, N. Y.

R. L. SACKETT, chairman, committee on merit system, AEC, former vice-president, ASME, Hotel White, New York, N. Y.

S. D. KIRKPATRICK, editor, *Chemical and Metallurgical Engineering*, 330 West 42nd Street, New York, N. Y.

W. B. PLANK, head of department of mining engineering, Lafayette College, Easton, Pa.

O. W. ESHBACH, Fellow, AIEE, Dean, Institute of Technology, Northwestern University, Evanston, Ill.

Specialized Engineering Committee

J. S. DODDS, *chairman*, vice-president, AEC, chairman, AEC committee on economic status of engineers, Box 207, Ames, Iowa.

S. P. LYLE, president, ASAE, Bureau of Agricultural Engineering, Department of Agriculture, Washington, D. C.

THOMAS URDAHL, consulting engineer, chairman, admissions committee, ASHVE, 722 Jackson Place, N. W., Washington, D. C.

H. D. KING, commissioner, Bureau of Lighthouses, Department of Commerce, Washington Society of Engineers, Washington, D. C.

H. T. WOOLSON, executive engineer, The Chrysler Corporation, past-president, SAE, Highland Park, Mich.

The memberships in these committees have been selected with reference to qualifications for formulating valuable opinion on civil service matters either through present or past employment in the government service, experience with merit systems in private industrial or educational fields, or demonstrated personal interest in and knowledge of the history and present problems of the civil service.

Federal Relations to Research

American Engineering Council over many years has interested itself in promotion of research as a fundamental and primary policy for the creation of new industries, the efficient improvement of technology, the increase of opportunities for employment, in general, the social and economic welfare of the nation. From time to time it has made specific fact-finding investigations.

This subject is actively before each Congress and the present Congress is no exception, several bills having been introduced in the House of Representatives. As would be natural, the main argument for government action in various directions for research this year rests upon the possibilities of increasing employment, since unemployment is a great national issue.

It is natural also that this subject should be approached from as many angles as the minds of the different authors of the bills suggest. Some of them tend to centralize and co-ordinate research into a sort of master agency of the Federal Government under whose sponsorship funds would be allocated in various ways both to government bureaus and semi-public agencies and to educational institutions. Such was the intent of H.R. 7939, the Randolph bill, so-called, proposed last year, on which no final action was taken.

Other bills, much more specific in character, concern themselves with the establishment of specific undertakings such as the four regional laboratories set up by last year's Congress under the direction of the Department of Agriculture for which $1,000,000 each was appropriated. Others are approached from the point of view that technology and the economic developments growing out of technology are responsible for the present unemployment. Suggestions have already been made to recommend the taxing of machinery as a method of balancing employment and technological advance.

In the preambles to the bills there is much confusion of terminology and much need for clarification of what is meant by the term research. Lyman J. Briggs, director of the National Bureau of Standards, in his leading discussion at the Detroit Forum of American Engineering Council on "Invention and the Engineer's Relation to It," suggests Julian Huxley's four categories of research. At one end is background re-

search, with no practical objective consciously in view as in the study of atomic physics. Next comes basic research, which must be quite fundamental in character but has some distant practical objective, such as the study of fluorescence; with the distant possibility of producing cold light. Third, there is *ad hoc* research with an immediate objective, such as research on discharge tubes for lighting purposes, and finally we have what industries call development or engineering research, which is the work needed to translate laboratory findings into full-scale commercial practice. As Huxley says, these categories overlap and interlock, but they form convenient pigeonholes.

American Engineering Council in early studies of this question has attempted to clarify, without official action, certain principles which may guide the authors of the many proposals to what seems to engineers to be the right relationship between the federal government and research. In these analyses it has seemed clear: (1) that the Federal Government may properly aid fundamental research in present federal bureaus and establishments; (2) that the Government may stimulate and assist research at educational institutions and such non-profit making laboratories as may be best prepared to serve the public; and (3) that these various aids should be so extended as not to interfere with private enterprise. Since it is obvious that the fundamental purpose of research can succeed practically so far as employment is concerned only when private industries individually accept this as a method of projecting new industry, the expansion of existing industry, the increase of employment in industry, and the steady distribution of the products of industry through reduction of cost.

The National Resources Committee has made several summaries of present projects but the committee approaches this total problem from the viewpoint of generalizing as to the values rather than projecting specific methods of accomplishment.

So far as the Federal Government is concerned these specific methods of accomplishment and the broader matter of philosophy outlined above take the form of bills introduced into Congress from the many points of view already indicated.

As pointed out by Doctor Briggs, the Federal Government is already spending several millions of dollars for research. It is evident, therefore, that we have a fact and not a theory.

The question then comes as to the practical methods whereby the Federal Government may by further grants of money extend the purposes and promote the fruits of research in terms of employment without confusion or duplication of effort. This is an enormously difficult question and most of the proposers of the various types of research legislation do not realize the complications and ramifications of their proposals.

Recent inquiries in informed governmental agencies seem to indicate that the present Congress is not disposed to add moneys to those already allocated to independent government agencies, semi-private non-profit institutions, or educational institutions, except on a 50-50 basis. It is moreover evident that any federal moneys must presuppose some federal control of those expenditures and here again there is confusion as to where this federal control should be placed. Of these newer proposals, according to one authority, the so-called Lea bill (H.R. 3652) comes closest to being in line with the principles stated above. However, there is doubt whether during this Congress any bills of this sort will reach actual consideration by vote.

One indication of this latter belief is found in the latest resolution on this subject (H. J. Res. 245) introduced in the House of Representatives on March 28 by Charles I. Faddis of Pennsylvania, in which a committee to be known as the Committee on Technological Unemployment is proposed; a sum of $200,000 is to be appropriated from the Treasury, of which $150,000 shall be available to the Secretary of Labor for the collection, preparation, and analysis of materials, and $50,000 for public hearings. It is proposed that the committee shall report its findings to the Congress on or before June 1, 1940. To date this joint resolution which must be passed by both the Senate and the House has not come to vote.

This whole subject needs leadership not now available, in part because of the diverse, sometimes competitive interests involved, and in part because the subject itself is so complex that it needs to be studied in the spirit made evident in certain findings of British commissions, with the intent of establishing a national policy for long-view objectives rather than piece-meal, confusing, and overlapping activities.

Future Meetings of Other Societies

Acoustical Society of America. Tenth-anniversary meeting, May 15–16, New York, N. Y.

American Association for the Advancement of Science. June 19–24, Milwaukee, Wis.

American Institute of Chemical Engineers. 31st semiannual meeting, May 15–17, Akron, Ohio.

American Institute of Mining and Metallurgical Engineers. 151st general meeting, July 10–13, San Francisco, Calif.

American Physical Society. 228th meeting, June 23–24, Princeton, N. J.

American Society for Testing Materials. 42d annual meeting, June 26–30, Atlantic City, N. J.

American Society of Civil Engineers. Annual convention, July 26–28, San Francisco, Calif.

American Society of Heating and Ventilating Engineers. Semiannual meeting, July 4–6, Mackinac Island, Mich.

American Society of Mechanical Engineers. Semiannual meeting, July 10–15, San Francisco, Calif.

American Society of Refrigerating Engineers. Spring meeting, May 21–22, Hershey, Pa.

Edison Electric Institute. Annual meeting, June 6–8, New York, N. Y.

Illuminating Engineering Society. 33d annual convention, August 21–25, San Francisco, Calif.

Institute of Radio Engineers. National convention, June 27–30, San Francisco, Calif.

International Conference on Large High-Voltage Systems (CIGRE). Tenth meeting, June 29–July 8, Paris, France.

National Electrical Manufacturers Association. May 14–18, Hot Springs, Va.

Society for the Promotion of Engineering Education. 47th annual meeting, June 19–23, State College, Pa.

Society of Automotive Engineers. World automotive engineering congress, May 22–28, New York, N. Y.; May 29–30, Indianapolis, Ind.; May 31–June 2, Detroit, Mich.; June 6–8, San Francisco, Calif.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and the other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Utility Engineering and Capital

To the Editor:

C. W. Kellogg's excellent article in the January issue, "Utility Engineering and Capital," loses some of its force when the reader begins to look for his nonexistent comments on certain unethical practices in the public-utility field. When one apple in a barrel has a rotten spot the proper cure is to take that one from the barrel and cut out the rot. Setting out another orchard across the road from the first one, at the expense of the taxpayers, is not fair either to reliable growers or to the taxpayers, and trying to cure a few rotten spots by that means is hardly proof of a logical mind. Yet it seems hardly more logical to attack biased legislation with an article that also is biased.

A frank facing of the problem, admitting the bad spots as well as asserting honesty where honesty and ethical practice have obtained, should be a prime part of such a discussion as Mr. Kellogg's. Presenting only one side of a problem has never yet led to a satisfactory solution of that problem; witness the existing "yardstick" which finds its only justification in minds that refuse to think a problem through.

The holding company, an important target of present legislation, has a legitimate economic function under certain conditions; for a group of small operating companies the holding company can cut costs, especially financing costs, by an amount almost unbelievable. Although the fact that state authorities permit a public utility to earn a specified return on all money spent for plant or betterments has led to the loading of costs in some instances, yet the practice of having one engineering company serve all plants in a given holding company is normally legitimate because it maintains proper standards at a minimum engineering cost. Ignoring or concealing the malpractice of a company or two in this matter is covering up the rotten spots and leaving the bad apples in the barrel to contaminate the sound ones. When visionaries are looking for excuses to push through their unsound schemes, such concealment is playing into the hands of the enemy.

We do not need to name the guilty companies, nor need we list all the specific abuses in the public-utility field.

What incentive has any company to continue its policy of honesty when foes attack all companies indiscriminately and friends whitewash the dishonest ones? What return can we expect from a defending article in a journal when watered valuations of actual physical plant and equipment sweep away its basic premise?

May we have another article, one that will admit all facts, face them, and suggest proper remedies for bad practice, in that way fighting the "yardstick" falsification with complete facts instead of with the "yardstick's" own method of partial concealment of fact?

Very truly yours,

H. H. KETCHAM (A'13, M'23)

(8 West Church Street, Bethlehem, Pa.)

Representations of the Synchronous Machine

To the Editor:

Some years ago I constructed and exhibited at Columbia University a simple mechanical device in which the relation between root-mean-square bus voltage e, short-circuit root-mean-square current i_s, transformed power p, and rotor angle ψ of a synchronous motor is represented in a novel and instructive way.

The device is shown in figure 1 and is diagrammed in figure 2 and represents Hopkinson's fundamental formula

$$p + i_s^2 r = ei_s \sin(\psi + \tan^{-1} r/\omega l) \qquad (1)$$

where r is the armature resistance and ωl the synchronous reactance for a round-rotor machine.

For a given excitation $i_s^2 r$ is a constant and is represented by a weight w while the power transformed p is represented by a weight W. Taking the radius of the pulley as unity and multiplying both sides of (1) by this unit, an equation in moments is obtained in which the clockwise moment is the weight A multiplied by $a \sin(\psi + \alpha)$ where $\alpha = \tan^{-1} r/\omega l$. To represent (1), let either A be the bus voltage in suitable units and the arm a the short-circuit root-mean-square current of the armature, or vice versa; the question of calibration of the arm a and of the mass-to-electrical units ratio for A being simple matters in either case. A right-hand pan is

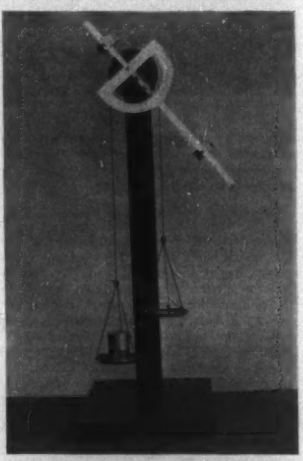

Figure 1

provided for the weight W when the machine is acting as a generator, that is, when p is negative. The weight w remains always in the left or motor pan.

At the pull-out motor load, $\psi + \alpha \geq \pi/2$ and the instrument becomes unstable and pulls out of balance. The phenomenon of a synchronous generator losing step with an infinite bus can be similarly exhibited. The phenomena of over-swing without loss of synchronism, or with only temporary loss of synchronism, resulting from sudden changes in load or bus voltage in the case of the synchronous motor have their dynamical analogies in the behavior of the device; parallelism in transient behavior between the two will be practically exact when the damping forces are the same.

Systems of synchronous machines may be represented by systems of these pendulum devices when certain servo mechanisms are provided. Also the device may be modified to take saliency accurately into account.

As shown in figure 3, the locus of p as a function of ψ is a limaçon and the locus of p', the synchronizing power, is a circle whose diameter ei_s is the diameter of the

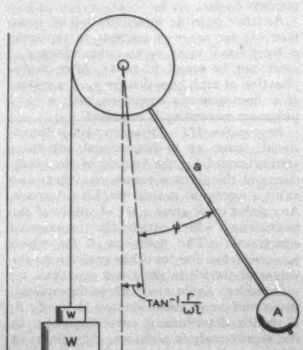

Figure 2

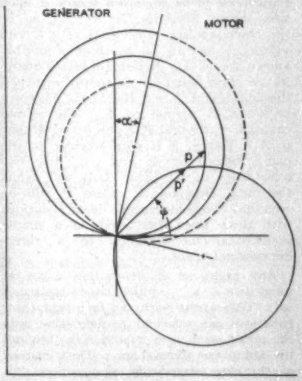

Figure 3

base circle of the limaçon. It is seen that p' decreases as p increases and becomes zero at pull-out and that p' is a maximum when p is zero, etc.

Very truly yours,

W. H. INGRAM

(New York, N. Y.; Member, American Mathematical Society)

Kirchoff's Equations in a Many-Dimensional Representative Space

To the Editor:

In line with the recent interest among the AIEE members in purely analytical modes of representation of electric-circuit relationships, using matrix algebra and tensor analysis, a geometrical interpretation of simultaneous linear equations may be opportune. A passive linear electric network is usually represented by such equations which express the two Kirchoff laws. Consider n simultaneous equations of the form

$$a_{1j}x_1 + a_{2j}x_2 + \ldots + a_{mj}x_m = b_j \qquad (1)$$

where j has all the integral values from 1 to n, and where in the general case m is not equal to n. The coefficients a may be real or complex numbers, or operational expressions containing derivatives with respect to time. By interpreting this system of equations, its determinants, and minors in terms of super-vectors and super-parallelopipeds in a many-dimensional

representative space, a new and different point of view is obtained, which may prove to be fruitful to the researcher and the student of the future.

We shall illustrate first, geometrically, the familiar case of $m = 3$, $n = 2$, and put the two b's equal to zero. This will give

$$\left.\begin{aligned} a_{11}x_1 + a_{21}x_2 + a_{31}x_3 &= 0 \\ a_{12}x_1 + a_{22}x_2 + a_{32}x_3 &= 0 \end{aligned}\right\} \quad (2)$$

Take the usual Cartesian system of three-dimensional orthogonal co-ordinate axes, X_1, X_2, X_3, and let x_1, x_2, x_3, be the projections of an unknown vector R upon these axes. Similarly, let a_{11}, a_{21}, a_{31} be the corresponding projections of a known vector A_1, and a_{12}, a_{22}, a_{32} those of another known vector A_2. In terms of vector analysis, the first equation (2) simply expresses the condition $A \cdot R = 0$, that is, the unknown vector R is normal to A_1. The second equation states that R is also perpendicular to A_2. Hence, R is perpendicular to the plane formed by A_1 and A_2. Any two other lines in the plane A_1A_2 will define the same direction R. Thus, it will be seen that two homogeneous linear equations with three unknowns admit of a simple geometrical interpretation in a three-dimensional space.

Any point on R determines a set of quantities x_1, x_2, x_3, which satisfy equations (2). This agrees with the fact that these equations are sufficient to determine only the ratios, such as x_1/x_3 and x_2/x_3, but not the unknowns themselves. Thus, instead of thinking analytically of equations (2), one need only imagine a plane determined by the given parameters a, and a direction normal to this plane. For example, let all the a's be ohmic resistances, and x_1, x_2, x_3, some unknown electric currents. In a representative three-dimensional space these resistances, or their equivalents, will form a plane, and R is a direction normal to this plane. Any point on R gives the values of the three unknown currents which satisfy the given Kirchoff equations. Incidentally, the same plane may be determined by an infinite number of pairs of vectors A or equations (2); this may be of interest to those engineers who are working on equivalent networks or transformation of networks.

Extending this geometric interpretation to a system of n homogeneous equations with $n + 1$ unknown quantities (all the b's still being equal to zero), the following proposition may be stated:

Proposition I. The n given sets of coefficients a determine n super-vectors in a representative $(n + 1)$ dimensional Euclidean space, and thus define an n-dimensional sub-space. The super-vector R of the $n + 1$ unknown quantities is normal to this sub-space.

In our ordinary space a line can be perpendicular only to another line or to a plane. In an N-dimensional space, an $N - q$ dimensional sub-space may be perpendicular to another sub-space of any number of dimensions, up to q. As a specific case above, a straight line may be normal to an $N-1$ dimensional sub-space. This means that the line is normal to any straight line lying within that sub-space.

Let now the number of homogeneous equations to which Proposition I refers be increased to $(n + 1)$. If the $n + 1$ vectors A form a space of $n + 1$ dimensions, a finite R perpendicular to it does not exist, and the only possible solution is $R = 0$. If a sub-space exists, of n or less dimensions, then at least one of the given equations is superfluous, and merely indicates that the $n + 1$ vectors A are not independent of one another. The reader can readily see this in the three-dimensional case: the three vectors A must be co-planar, and any of them may be linearly composed of the other two.

In a more general system of nonhomogeneous equations (1) when all the b's are not equal to zero, consider again the three-dimensional case first ($n = m = 3$). The familiar solution for x_1 is

$$x_1 = (b_1m_1 + b_2m_2 + b_3m_3)/D,$$

where D is the determinant formed of the a's, and the m's are its three cofactors not containing the coefficients of x_1. But it is known from vector analysis that D is the volume of a parallelopiped built on the vectors $A_1A_2A_3$. Similarly, $b_1m_1 + b_2m_2 + b_3m_3$ is the volume of the parallelopiped built on B, A_2, A_3, where B is the vector whose components are b_1, b_2, b_3. Thus, the given system of three equations admits of the following geometric interpretation: Imagine four parallelopipeds constructed on the vectors A_1, A_2, A_3, B, taken three at a time. Let their volumes be D, D_1, D_2, D_3, respectively. Then

$$x_1 = D_1/D;\ x_2 = D_2/D;\ x_3 = D_3/D \quad (3)$$

This solution fails when $D = 0$, that is, when the three A's happen to be co-planar. In this case the equations are inconsistent with each other.

Proposition II. When there are n simultaneous nonhomogeneous equations, the equations (3) may be generalized and interpreted geometrically in an n-dimensional representative space, using n-dimensional super-parallelopipeds. It is shown in many-dimensional geometry that their volume is also numerically equal to the corresponding determinants built of the projections of their edges, $A_1A_2, \ldots, A_n$. The $(n + 1)$st vector, B, consists of the components $b_1, b_2, \ldots, b_n$.

Another possible interpretation of equation (1) for $m = n$ consists in replacing x_1 by y_1/y_{n+1}, x_2 by y_2/y_{n+1}, etc., where y_{n+1} must not be equal to zero. After multiplication of each equation by y_{n+1}, a system of n homogeneous equations with $n + 1$ unknown quantities is obtained.

Proposition III. In an $(n + 1)$ dimensional space an n-dimensional sub-space exists, formed by the vectors of the coefficients of the given n equations; there also exists a vector R normal to this sub-space. Any point on R gives a set of values of the unknowns y which satisfy the transformed equations. The point on R for which $y_{n+1} = 1$ has for its other projections the values of the x's in the given equations.

Consider again our three-dimensional space and some three vectors in it, A, B, C, which determine a parallelopiped. In the vector-analysis notation, the volume of this parallelopiped is $(A \times B) \cdot C$, where

$$A \times B = (a_2b_3 - a_3b_2)i + (a_3b_1 - a_1b_3)j + (a_1b_2 - a_2b_1)k \quad (4)$$

where i, j, k, are unit vectors along the three axes, respectively. This expression represents the area of the base AB of the parallelopiped ABC. The three areas within the parentheses in equation (4) are the projections of the base AB upon the co-ordinate planes YZ, ZX, and XY, respectively. The same expressions are three of the minors of the determinant consisting of the nine projections of the vectors A, B, C. The dot and the cross in the expression $(A \times B) \cdot C$ are interchangeable, and so are the letters themselves, so long as their cyclic order is preserved. Thus, we have the following relationship in a three-dimensional space: Any three non-co-planar vectors form a parallelopiped whose volume is numerically equal to the determinant formed of the projections of these vectors. The first minors of this determinant are numerically equal to the projections of the corresponding base of the parallelopiped upon the three co-ordinate planes. With a suitable convention as to the order of the vectors, the signs of the analytical expressions can be made to agree with those of their geometrical equivalents.

When extending this relationship to more than three simultaneous equations, that is, to many-dimensional spaces, it is necessary to keep in mind the number of co-ordinate sub-spaces of different orders. In an n-dimensional space there can be imagined n axes of co-ordinates at right angles to each other. Any k of these will form a co-ordinate sub-space of order k. The number of combinations of n objects taken k at a time is

$${}_kC_n = n(n-1)\ldots(n-k+1)/k!$$

This is the number of co-ordinate sub-spaces of order k. The following table gives a few common values of ${}_kC_n$.

n	$k=1$	$k=2$	$k=3$	$k=4$	
3	3	3			
4	4	6	4		
5	5	10	10	5	

It will be readily seen that these values are those of the non-extreme coefficients in a binomial expansion. For example:

$$(x + 1)^4 = x^4 + 4x^3 + 6x^2 + 4x + 1$$

Thus, in a four-dimensional space there are four co-ordinate axes, six co-ordinate planes, and four three-dimensional co-ordinate sub-spaces. When projecting a four-dimensional super-parallelopiped on such co-ordinate sub-spaces, it is necessary to specify the number of dimensions used. For example, an edge of a four-dimensional super-parallelopiped may be projected upon the four axes, upon the six planes, or upon the four three-dimensional sub-spaces. Each side of the super-parallelopiped may be projected either upon the six co-ordinate planes or upon the four co-ordinate bodies. Each of the eight three-dimensional bodies delimiting the super-parallelopiped may be projected upon any of the four co-ordinate bodies. As the number of space dimensions increases, the possible number of projections also increases quite rapidly.

Proposition IV. In a space of any number of dimensions, n, the volume of a super-parallelopiped is numerically equal to the determinant made of the projections

of the vectors which form the edges of this parallelopiped. If the vectors are not independent of one another but form a subspace of not more than $n - 1$ dimensions, the volume of the super-parallelopiped is zero, and so is the value of the determinant.

Proposition V. A set of minors of any order k gives the numerical values of the projections of the k-dimensional members of the parallelopiped upon the co-ordinate bodies of that number of dimensions. A Laplace's development of the determinant by the k and $n - k$ rows may be geometrically interpreted as the volume of the super-parallelopiped expressed as the scalar product of its kth and $(n - k)$th elements. In the simplest case, the volume of an ordinary three-dimensional parallelopiped is equal to a scalar product of its base $A \times B$ and the third edge C. Here $A \times B$ is to be thought of as a vector normal to the plane AB.

It is hoped that these propositions, given here without proofs, may stimulate younger scientifically inclined electrical engineers to study n-dimensional spaces, with the idea of using them as representative spaces in advanced circuit problems and other pioneer investigations in our profession. Such a mode of representation has been found valuable, for example, in statistical mechanics of large aggregates of particles.

Very truly yours,

VLADIMIR KARAPETOFF (A'03, F'12)

(Consulting Engineer, Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.)

Personal Items

O. W. Eshbach (A'17, F'37) has been appointed dean of the new Institute of Technology at Northwestern University, Evanston, Ill. Born in Pennsburg, Pa., 1893, he graduated from Lehigh University in 1915 with the degree of electrical engineer. During the next year he was an assistant to the chief engineer at the United States Naval Engineering Experiment Station, Annapolis, Md., where he also spent the summer of 1917. He entered the United States Army in November 1917, serving as a second lieutenant in the Signal Corps and a radio instructor for officer candidates. In 1919 he returned to Lehigh University, where he had been an instructor in electrical engineering and a graduate student in 1916 and 1917, and continued in both capacities, receiving the degree of master of science and promotion to an assistant professorship in 1920. In 1923 he became assistant engineer for the Bell Telephone Company of Pennsylvania, Philadelphia, engaged in college relations and student training, and in 1925 was employed in a similar capacity as special assistant in the personnel department, American Telephone and Telegraph Company, New York, N. Y. In that position, where he continued until his recent appointment, he was supervisor of the Bell System option of Massachusetts Institute of Technology co-operative course in electrical engineering and non-resident instructor at MIT; he also served as instructor in the night graduate school of electrical engineering of Brooklyn (N. Y.) Polytechnic Institute. He was editor-in-chief of "Handbook of Engineering Fundamentals" published by John Wiley and Sons, New York, 1936. He is a member of the AIEE publication committee and of the committee on education (chairman, 1935-7) and has been active on several other committees. He is also a member of the Society for the Promotion of Engineering Education, the Engineers' Council for Professional Development, Sigma Xi, and Eta Kappa Nu.

O. W. ESHBACH

H. B. Brooks (A'09, F'31) retired February 1, 1939, as physicist and chief of the electrical instrument section of the National Bureau of Standards, Washington, D. C. Born in 1869 in New Bremen, Ohio, Mr. Brooks was employed by the Edison Electric Illuminating Company of Piqua, Ohio, in 1886, and the following year, after three months in the testing room of the Edison Machine Works at Schenectady, N. Y. (forerunner of the General Electric Company), he was made superintendent and electrician of the plant. He resigned in 1898 to attend Ohio State University, where he received the degree of mechanical engineer in electrical engineering in 1903, having served as student assistant both in physics and in electrical engineering during his course. Upon graduation he became a laboratory assistant in the Bureau of Standards, advancing through various grades to the position he held at retirement. He was the first chief of the electrical-instrument section, assuming the position in 1906. He received the degree of doctor of philosophy from Johns Hopkins University in 1926, for work in electrical engineering. Since 1919 he has been a member of the Institute's committee on instruments and measurements, taking an active part in the establishment of standards. He is the author of many papers on technical subjects.

R. H. Burcher (A'19, M'20) plant operation engineer in the department of operation and engineering, American Telephone and Telegraph Company, New York, N. Y., retired March 21, 1939, on the 39th anniversary of his employment in the Bell System. A native (1878) of Dunkirk, N. Y., Mr. Burcher attended the State Normal School at Fredonia, N. Y., and in 1900 was employed in outside-plant work by what was then the New York and New Jersey Telephone Company. He was appointed division plant engineer for the Long Island division of the New York Telephone Company in 1907, and division construction superintendent in 1912. In 1914 and 1915 he was engaged in inventory and appraisal work on rate-making cases for Bell Telephone properties in Pennsylvania and New York, and in 1915 joined the general engineering staff of the American Telephone and Telegraph Company, becoming plant operating methods engineer in 1917 and outside plant engineer in 1919. He was appointed an assistant vice-president in 1920, and in 1927 assumed the position of plant operation engineer, which he held until retirement.

H. S. Osborne (A'10, F'21) has been appointed operating results engineer in the department of operation and engineering, American Telephone and Telegraph Company, New York, N. Y. A native (1887) of Fayetteville, N. Y., Doctor Osborne received the degree of bachelor of science in electrical engineering in 1908, and that of doctor of engineering in 1910 from Massachusetts Institute of Technology. He entered the engineering department of the American Telephone and Telegraph Company in 1910, and became assistant to the transmission and protection engineer in 1914. From 1920 until his recent appointment he was transmission engineer. Doctor Osborne is a director of the Institute, chairman of the technical program and award of Institute prizes committees, and member of several other Institute committees. He is also active in other technical societies, and is the author of many articles on technical subjects.

H. S. OSBORNE

J. D. Preston (M'37) has been made general manager of the Cliffs Power and Light Company, Ishpeming, Mich. A native (1898) of Paris, Tex., Mr. Preston was graduated

L. G. WOODFORD J. R. SHEA J. D. PRESTON A. L. COOK R. H. KNOWLTON

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from the University of Texas in 1921 with the degree of bachelor of science in electrical engineering, and received the degree of master of science in electrical engineering from Massachusetts Institute of Technology in 1923. While working for the latter degree, he was an assistant instructor in the department of electrical engineering at MIT. In 1923 and 1924 he was a student engineer with the Texas Construction Company at Dallas, Tex., and for the following two years he was an engineer for the Cia Cubana de Electricidad, Inc., Havana, Cuba. In 1926 he became superintendent of distribution for the Central Power and Light Company, San Antonio, Tex., and in 1929 superintendent of the electrical department of the Columbus, Delaware, and Marion Electric Company, Marion, Ohio. He was employed in the engineering department of the Florida Power and Light Company at Miami in 1933 and the following year became head of the rate department, continuing in that position until his recent appointment.

J. R. Shea (M'30) has been appointed manager of the Point Breeze works of the Western Electric Company at Baltimore, Md. Born at Fiske, Wis., in 1886, Mr. Shea received the degree of bachelor of science in electrical engineering at the University of Wisconsin in 1909. He entered the student course at the Hawthorne works of Western Electric, Chicago, Ill., the same year, and has continued with the company ever since. He became chief of production branch methods at the Hawthorne works in 1915. In 1918 he went to the Orient as advisor on manufacturing methods to the Nippon Electric Company, Tokyo, Japan, and the China Electric Company, Shanghai, returning to the United States in 1919 to become assistant division chief in the technical branch at Hawthorne. He was made assistant superintendent of development in 1922, and superintendent of manufacturing development in 1927. From 1929 until his present appointment he was assistant engineer of manufacture at the company's Kearny, N. J., works.

J. B. Harris, Jr. (A'17) has been appointed vice-president of the Rumsey Electric Company, Philadelphia, Pa. Born March 7, 1890, at Hinton, W. Va., he graduated from Bliss Electrical School, Washington, D. C., in 1911. He was associated as a sales engineer with General Electric Company, Westinghouse Electric and Manufacturing Company, and the Pittsburgh Transformer Company, Pittsburgh, Pa., later becoming a field engineer for the last-named company. In 1920 he became a member of the firm of Harris and Evans, Philadelphia, Pa., which later became Harris and Butler. Mr. Harris became president of the latter firm, continuing in this position until 1935, when he was made manager of the electrical-equipment department of the Rumsey Electric Company. He held that position until his present promotion. He is a junior past chairman, AIEE Philadelphia Section.

A. L. Cook (A'02, M'13) has been appointed director of the school of science and engineering at Pratt Institute, Brooklyn, N. Y. He has been acting director since May 1938, and for 25 years before was head of the electrical-engineering department of the school. A biographical sketch of Mr. Cook appeared in the July 1938 issue (pages 320–1) when he assumed the acting directorship of the school.

L. G. Woodford (M'31) has been appointed plant operation engineer in the department of operation and engineering of the American Telephone and Telegraph Company, New York, N. Y. Born in Waterloo, Iowa, in 1888, he studied mining engineering at Iowa State College and was employed by the Iowa Telephone Company, Des Moines, in 1911, becoming appraisal engineer in 1914. In 1916 he was employed as an appraisal engineer by the Northwestern Bell Telephone Company, Omaha, Nebr., and five years later became engineer of costs and practices for that company. He came to the American Telephone and Telegraph Company in 1923, becoming plant inventory and costs engineer in 1927, plant extension engineer in 1933, and in 1935 operating results engineer, the position he held until his recent promotion.

R. H. Knowlton (A'12) has been made executive vice-president and general manager of the Connecticut Light and Power Company, Hartford, Conn. A native (1882) of Trenton, N. Y., Mr. Knowlton graduated in civil engineering at Cornell University in 1906. Employed 1907–09 by Standard Electric Construction Company, Rochester, N. Y., and 1909–10 by General Electric Company, Cincinnati, Ohio, in 1910 he became a salesman of industrial power for the United Gas Improvement Company, Philadelphia, Pa. He was later appointed industrial engineer, then power engineer, and finally assistant to the vice-president of that company. He joined the Connecticut Light and Power Company in 1926 as assistant to the president, becoming a vice-president the following year.

C. E. Ide (A'16, M'38) recently was elected president of the Southeastern Electric Exchange. Mr. Ide has been vice-president and general manager of the East Tennessee Light and Power Company, Bristol, since 1927 and has held the same position in the Tennessee Eastern Electric Company, also at Bristol, since 1928. After graduating from Iowa State College in 1914 with the degree of bachelor of science in electrical engineering, he was employed in engineering capacities by utility companies in Denver, Colo., Toledo, Ohio, and Meridian, Miss., and as statistical engineer by Henry L. Doherty and Company, New York, N. Y. In 1919 he became assistant electrical engineer for the latter company, and in 1922 assistant to the chief engineer in charge of public utility operations, remaining in that position until 1927.

Glen Ireland (M'31) has been appointed transmission engineer by the American Telephone and Telegraph Company, New York, N. Y. After graduating from the University of Iowa in 1917 with the degree of bachelor of science in electrical engineering, Mr. Ireland spent two years in the United States Army as radio and telephone officer. He then became a telephone engineer for Northwestern Bell Telephone Company, Des Moines, Iowa, and in 1923 entered the plant engineering division of the department of operation and engineering, American Telephone and Telegraph Company. Before his recent appointment he was engineer in charge of the maintenance group in the plant engineering division.

R. B. McKinley (A'27) has been appointed service engineer for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. He will be located with the Westinghouse staff at the New York World's Fair at present. Mr. McKinley was formerly design engineer in the electrical-engineering department of the Union Switch and Signal Company, Swissvale, Pa.

L. M. Robertson (A'27) has been appointed chairman of the engineering section of the

Rocky Mountain Electrical League for 1939. He is transmission and station engineer for the Public Service Company of Colorado, with headquarters at Denver.

T. W. Swartz (A'35) has been made superintendent of the underground department of the Hawaiian Electric Company, Honolulu. He was formerly assistant superintendent, underground department, Northwestern Electric Company, Portland, Ore.

W. H. McKinley (A'37) has been made second vice-president of the Electric Club of San Diego, Calif., and chairman of its membership committee. He is chief electrician of the City of San Diego.

E. E. Shaffer (A'37) has been elected a director of the Electric Club of San Diego, Calif. He is electrical inspector for the City of San Diego.

Obituary

Clarence Floyd Hirshfeld (A'08, F'36) died in Detroit, Mich., April 19, 1939. He was chief of the department of research of The Detroit Edison Company. Born January 30, 1881, at San Francisco, Calif., he received the degrees of bachelor of science in electrical engineering from the University of California in 1902, master of science in mechanical engineering from Cornell University in 1905, and the honorary degree of doctor of engineering from Rensselaer Polytechnic Institute in 1932 and from the University of Detroit in 1938. He became an instructor at Cornell University, Ithaca, N. Y., in 1903, later becoming assistant professor and professor of mechanical engineering. During this period and later he carried on engineering consultant practice. In 1914 he was appointed by the Detroit Edison Company to the position of chief of the research department which he held for the rest of his life. He organized the department, one of the first established by an electricity supply company. During the World War he was a lieutenant-colonel in the United States Army Ordnance Department. He was chairman of the Engineers' Council for Professional Development from its organization until 1935, and at the time of his death was president of Utilities Co-ordinated Research, Inc., an organization formed by a group of electric utility companies. He was a member of many technical societies, author of several books and many articles on technical subjects, and had served on the AIEE committees on power generation, standards, and electrical machinery. In 1937 he was awarded the Worcester Reed Warner Medal of The American Society of Mechanical Engineers.

William Amzi Dick (A'02, M'04, F'13) retired, died at Wilkinsburg, Pa., December 5, 1938, according to information recently received. Associated for 43 years with the Westinghouse Electric and Manufacturing Company, Mr. Dick made valuable contributions to the electrical industry in the design of d-c motors. He was born September 19, 1866, at Geneva, Ohio, and received the degree of bachelor of arts at Oberlin College in 1890 and that of mechanical engineer in electrical engineering from Cornell University in 1892. Following graduation he entered the student course of the Westinghouse Company, then at Pittsburgh, Pa., becoming inspector of the detail department the same year. In 1895, about the time the company moved to East Pittsburgh, Pa., he became foreman of the detail testing department and in 1898 engineering correspondent of the engineering department. He was transferred in 1899 to the Walker Company, Cleveland, Ohio, a subsidiary of the Westinghouse Company, as electrical engineer in charge of electrical and mechanical design, returning to East Pittsburgh in 1901 as designer of d-c machines. In 1912 he was appointed an application and sales engineer. In 1924 he became superintendent of extension courses, developing courses relating to the electrical industry for the use of employees and others. He continued in that position until his retirement in 1935. In addition to the courses of study, Mr. Dick was the author of papers on technical subjects and other writings on the electrical industry. He was the first chairman (1922–23) of the AIEE Springfield, Mass., Section.

Thomas Alfred Panter (A'03, M'13, F'26) engineer in charge of operations of the Bureau of Power and Light, City of Los Angeles, Calif., died March 12, 1939. He was born in Manchester, England, September 29, 1876, and studied electrical engineering at Ohio State University, leaving during his fourth year because of ill health. From 1902 to 1905 he was engineering assistant to the superintendent, Niagara Falls (N. Y.) Power Company. In 1905 he was employed by the Pacific Light and Power Company, Los Angeles, Calif.; during the following year he was superintendent of the Ontario (Calif.) Power Company, but in 1907 he returned to the former company. In 1908 he began design and engineering work in connection with the Los Angeles aqueduct, and from 1910 to 1916 was engaged in design and construction for the Los Angeles municipal power system. With the organization of the city's Bureau of Power and Light in 1916, Mr. Panter was made engineer in charge of operations, a position he held until his death, acting also as chairman of the advisory committee for the Bureau. In 1935 he spent some time in Washington, D. C., serving as an advisor on the organization of the United States Rural Electrification Administration. He was appointed in 1938 chief engineer to the special joint Congressional committee investigating the Tennessee Valley Authority, and had submitted his report only a short time before his death.

Charles Benjamin Coates (A'03, M'13) electrical engineer, Chicago Pneumatic Tool Company, Cleveland, Ohio, died March 17, 1939. Mr. Coates was born January 4, 1870, at Erie, Pa., was educated there, and spent four years (1887–91) as an apprentice machinist with the Bay State Iron Works of Erie. From 1891 to 1894 he was a journeyman machinist for the Keystone Electric Company in the same city. The years 1894 to 1896 were spent studying mathematics and physics at Syracuse University, and electrical engineering at Cornell University. In 1896 he became chief draftsman for the Keystone Electric Company at Erie, in 1900 superintendent, and in 1902 electrical engineer. Several years later he was employed as electrical engineer by the Chicago Pneumatic Tool Company, Chicago, Ill., and continued with that company as manager of the electrical department first in Chicago, later in Erie, Pa., and as chief electrical engineer in Erie and in Cleveland, Ohio, until his death.

Royal R. Crates (A'37) chief of underground division, Light and Water Commission of the City of Memphis, Tenn., died March 10, 1939, in Fort Wayne, Ind. Mr. Crates was born at Monroeville, Ind., January 10, 1900, and graduated from Purdue University, Lafayette, Ind., in 1922, with the degree of bachelor of science in electrical engineering. From 1922 to 1924 he was employed as an engineer in the electrical distribution department of Consumers Power Company, at Jackson, Mich., and 1924–27 as assistant distribution engineer in charge of underground distribution for the operating companies of the Commonwealth Power Corporation. In 1927 he became division engineer for Consumers Power Company at Kalamazoo, Mich., continuing in that position until 1936, when he entered the employ of the City of Memphis Light and Water Commission as assistant chief engineer of the lighting division, later assuming the position which he held at the time of his death.

John Edmund Cammack (A'19), assistant engineer, Potomac Electric Power Company, Washington, D. C., died in March 1939. He was born April 12, 1889, in Washington, D. C. He attended Mount St. Mary's College, Emmitsburg, Md., receiving the degrees of bachelor of arts in 1911 and master of arts in 1914, and studied engineering at the Catholic University of America, Washington, receiving the degree of bachelor of science in electrical engineering in 1916. During the World War he did radio and telephone work in the Signal Corps of the United States Army. After discharge from the Army, he was employed in the electrical-engineering department of the Potomac Electric Power Company, where he remained, as junior engineer, and later as assistant engineer, until his death.

Edgar Strasburger (A'03) died recently at White Plains, N. Y. Born in New York, N. Y., March 21, 1873, Mr. Strasburger received the degree of bachelor of science at the College of the City of New York in 1894 and the degree of electrical engineer in mechanical engineering at Cornell University in 1896. He became an assistant in the cable department of Western Electric Company, New York, in 1896, and later was made superintendent of the company's cable department in London, England. In 1916 he was appointed general superintendent of the Standard Underground Cable Company, Ltd., at Hamilton, Ont., Canada, and some years later became works manager of The Standard Underground Cable Company, St. Louis, Mo.

Membership

Recommended for Transfer

The board of examiners, at its meeting on April 20, 1939, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Blume, L. F., assistant engineer, General Electric Company, Pittsfield, Mass.

DeBeech, A. V., electrical engineer, Canadian and General Finance Company, Ltd., Toronto, Can.

Tucker, C. E., professor of electrical engineering, Massachusetts Institute of Technology, Cambridge.

Warner, R. W., professor of electrical engineering, University of Texas, Austin.

4 to Grade of Fellow

To Grade of Member

Allen, J. B., chief of tests, Pennsylvania Water and Power Company, Baltimore, Md.

Anderson, J. W., engineer, system planning, Philadelphia Electric Company, Philadelphia, Pa.

Diehl, C. W., general foreman, Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Kelly, M. M., vice-president, in charge of engineering, Breeze Corporations, Inc., Newark, N. J.

Farrow, A. P., acting electrical engineer, Knoxville Electric Power and Water Board, Knoxville, Tenn.

Pergg, W. F., engineering inspector, Consolidated Edison Company of N. Y., Inc., New York, N. Y.

Flegal, B. C., division electrical superintendent, Oklahoma Gas and Electric Company, Enid.

Fochs, H. N., assistant electrical engineer, Gibbs and Cox, Inc., New York, N. Y.

Housley, J. E., superintendent of power, Aluminum Company of America, Alcoa, Tenn.

Leonard, C. E., senior switchman, Illinois Bell Telephone Company, Urbana.

McDonald, J. A., superintendent of service shop, General Electric Company, Salt Lake City, Utah.

O'Brien, J. R., assistant professor of electrical engineering, The Catholic University of America, Washington, D. C.

Olmsted, L. M., division engineer, Duquesne Light Company, Pittsburgh, Pa.

Perry, L. P., consulting engineer, St. Petersburg, Fla.

Rockey, C. H., superintendent, Municipal Utilities, Alliance, Nebr.

Stevens, W. P., chief engineer, Wm. G. Morrison, Waco, Tex.

Stewart, H. R., protection engineer, New England Power Service Company, Boston, Mass.

Tehinnis, P. M., chief engineer, Samson United Corporation, Rochester, N. Y.

Thomas, C. U., operating supervisor, Duquesne Light Company, Pittsburgh, Pa.

Thomson, L. P., maintenance superintendent, Ducilo S. A. Productors de Rayon, Argentina, South America.

Whitehead, E. R., supervisor, Duquesne Light Company, Pittsburgh, Pa.

Wyland, E. E., general plant supervisor, Mountain States Telegraph and Telephone Company, Denver, Colo.

Young, F. B., sales engineer, Westinghouse Electric Supply Company, Salt Lake City, Utah.

23 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before May 31, 1939, or July 31, 1939, if the applicant resides outside of the United States or Canada:

United States and Canada

Baldwin, D. R., Aluminum Company of America, Alcoa, Tenn.

Ballin, A. E. (Member), 2005 Philtower Building, Tulsa, Okla.

Barnes, C. O., Southwestern Bell Telephone Company, Tulsa, Okla.

Barr, R. R., 261 Emerson St., Pittsburgh, Pa.

Brooks, C. R., Aluminum Company of America, Alcoa, Tenn.

Bruckman, W. C., Westinghouse Electric and Manufacturing Company, Mansfield, Ohio.

Byars, L. T. (Member), Union Electric Company of Missouri, St. Louis.

Cambridge, C. G., Signal Corps Laboratories, Fort Monmouth, Oceanport, N. J.

Carver, L. A., Works Progress Administration, Trenton, N. J.

Corbett, C. W., WBO Broadcasting Corporation, New York, N. Y.

Cross, J. W. (Member), Memphis Power and Light Company, Memphis, Tenn.

Dee, E. L. (Member), General Electric Company, Salt Lake City, Utah.

Deming, J. W., Memphis Light, Gas, and Water Division, Memphis, Tenn.

Dempwolf, C. J., Carlile and Doughty, Inc., Conshohocken, Pa.

Denton, S. M., United States Bureau of Reclamation, Denver, Colo.

Denyer, A. G., Southern California Edison Company, Ltd., Alhambra, Calif.

Dickerson, H. A., Jr., American Steel and Wire Company, Donora, Pa.

Donovan, J. D., Board of Public Utilities, Kansas City, Kans.

Doolittle, R. C., Jr., Maquoketa Valley Rural Electric Cooperative, Anamosa, Iowa.

Dunham, A. W., Anaconda Wire and Cable Company, Ltd., Alhambra, Calif.

Farquhar, W. N., Aluminum Company of America, Massena, N. Y.

Few, W., General Electric Company, Fort Wayne, Ind.

Franki, P. W., Continental Electric Company, Newark, N. J.

French, S. F. (Member), Anaconda Copper Mining Company, Hastings-on-Hudson, N. Y.

Frey, A. P., Baltimore Transit Company, Baltimore, Md.

Gantt, J. S., General Electric Company, West Lynn, Mass.

Garrison, J. M., State Water Conservation Board, Helena, Mont.

Glaze, H. C., Jr., General Electric Company, Portland, Ore.

Goodell, M., Armstrong Tire and Rubber Company, Natchez, Miss.

Gostin, B. F., Tennessee Valley Authority, Wilson Dam, Ala.

Graham, D. C., General Electric Company, Pittsfield, Mass.

Guenther, F. G. H., Utah Power and Light Company, Salt Lake City.

Haley, J. L., Memphis Light and Water Division, Memphis, Tenn.

Henry, E. B. (Member), Tennessee Valley Authority, Knoxville, Tenn.

Herring, F. M., Baltimore Transit Company, Baltimore, Md.

Higgins, C. H., General Electric Company, Philadelphia, Pa.

Hill, A. J., Montana State College, Bozeman.

Hulsizer, J. E., 41 Lenox Avenue, East Orange, N. J.

Jeffrey, A. T., English Electric Company, St. Catharines, Ont., Canada.

Jeffers, L. M., Jr., Stanford University, Stanford University, Calif.

Jenner, R. R., 1737 Mississippi, Lawrence, Kans.

Johnson, M. S. (Member), Southern Bell Telephone and Telegraph Company, Atlanta, Ga.

Johnson, W. T., The Nevada-California Electric Corporation, El Centro, Calif.

Juhnke, B. J., Jr., Line Material Company, South Milwaukee, Wis.

Kallendorf, C. E., Cincinnati Gas and Electric Company, Cincinnati, Ohio.

Kaufmann, F. W., Federal Power Commission, New York, N. Y.

Kiefer, J., Aluminum Company of America, Alcoa, Tenn.

Kingsbury, C. R. (Member), Ohio Brass Company, Seattle, Wash.

Kirkwood, G. B. (Member), Pacific Electric Manufacturing Corporation, Los Angeles, Calif.

Kostic, W. B., 3250 Ludlow Street, Philadelphia, Pa.

Lautz, P. O., Atchison, Topeka and Santa Fe Railway Company, Topeka, Kans.

Long, C. E., Aluminum Company of America, Alcoa, Tenn.

Loy, J. McN., Pennsylvania Railroad Company, New York, N. Y.

Marvin, A. L., B. M. T. Corporation, Brooklyn, N. Y.

Masterson, R. C., Puget Sound Navy Yard, Bremerton, Wash.

Mazerall, E. W., Canadian Westinghouse Company, Ltd., Hamilton, Ont., Canada.

McKeon, J. B., Public Service Electric and Gas Company, Irvington, N. J.

Miller, M. L., Muzak Corporation, New York, N. Y.

Miller, R. I., Public Service Company of Northern Illinois, Wheaton, Ill.

Moore, W. A., New York, New Haven and Hartford Railroad Company, New Haven, Conn.

Mueller, F. G. (Member), Commonwealth Edison Company, Chicago, Ill.

Muhleman, R. R., Atlantic Refining Company, Philadelphia, Pa.

Norman, W. H., American Telephone and Telegraph Company, New York, N. Y.

Oschwald, B., Cleveland Electric Illuminating Company, Cleveland, Ohio.

Ott, M. G., Board of Public Utilities, Kansas City Kans.

Page, R. G., Standard Oil Company, San Francisco, Calif.

Popoff, J. P. (Member), Route 1, Box 133, Cudahy, Wis.

Reid, C. R., Central Ohio Light and Power Company, Wooster, Ohio.

Row, W. E., Southern California Edison Company, Los Angeles, Calif.

Rue, H. E., The Hoover Company, North Canton, Ohio.

Schmidt, F. R., The Mountain States Telephone and Telegraph Company, El Paso, Tex.

Schuck, C. L., General Electric Company, Philadelphia, Pa.

Scott, J. A., United States Treasury Department, Washington, D. C.

Shaw, C. H. (Member), care Maurice R. Scharff, New York, N. Y.

Sherlock, H. G., Mountain States Telephone and Telegraph Company, Denver, Colo.

Simpson, J. H., National Research Council, Ottawa, Canada.

Slater, F. M., Rural Electrification Project, Bowling Green, Ky.

Steiner, W. W., Navy Yard, Mare Island, Vallejo, Calif.

Tallman, S. R., Narragansett Electric Company, Providence, R. I.

Tesar, J. J., Cleveland Electric Illuminating Company, Cleveland, Ohio.

Towers, W., Narragansett Electric Company, Westerly, R. I.

Vance, P. A., General Electric Company, Fort Wayne, Ind.

Van Kleeck, R. B., Philadelphia Electric Company, Philadelphia, Pa.

Van Wambeck, S. H., Rice Institute, Houston, Tex.

Venegas, C., 228 East Fifth Street, Chester, Pa.

Wann, W. I. (Member), University of California, San Francisco.

Webster, A. D. (Member), Orrville Municipal Utilities, Orrville, Ohio.

Welf, R. H., Ohio Power Company, Coshocton.

Williams, W. A., General Electric Company, Pittsfield, Mass.

Yearout, R. McD., Midwest Electric Co-operative, Inc., Rotan, Tex.

Total, United States and Canada—90

Elsewhere

Campos, R. S., Puerto Rico Rural Administration, Ponce, Puerto Rico.

Gantt, C. H., Standard Oil Company of New York, Caripito, Venezuela, South America.

Holtane, G. C., Lago Oil and Transport Company, Ltd., Aruba, Netherlands West Indies.

Miatt, J., Department of Road Transport and Tramways, Sydney, N. S. W., Australia.

Pickles, T., Borough of Ilford Electricity Department, Ilford, Essex, England.

Total, elsewhere—5

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Coleman, Irwin M., 581 Academy St., New York, N. Y.

Cory, Harold M., 270 Washington Ave., Albany, N. Y.

Ebert, Kenneth W., 776 N. Cass St., Milwaukee, Wis.

Ember, Theodore, 4011 Springdale Ave., Baltimore, Md.

Garvey, Fred A., Brownsville, Tenn.

Johnson, Harold M., 2604 Fenwood Road, Houston, Texas.

Johnson, James Steven, 213 Buckingham St., Hartford, Conn.

Lewis, Rodney C., 310 Garland Ave., Takoma Park, Md.

McWhorter, W. Allen, Jr., 4549 Lake Park Ave., Chicago, Ill.

Straley, Munro R., Soldier, Pa.

Strauss, Walter A., 39 West 69th St., New York, N. Y.

Van Bylevelt, J. S., 220 E. 204th St., New York N. Y.

12 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Society Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

PATENT TACTICS AND LAW (Revised Edition of PATENTS). By R. S. Hoar. New York, Ronald Press Company, 1939. 315 pages, 9 by 6 inches, cloth, $4.50. Contains an analysis and interpretation of enough of the patent law to enable an industrial executive or engineer to cooperate with his patent attorney. Definitions, patentability, search procedure, litigation policies and maneuvers, and the organization of a patent department are discussed in nontechnical language.

METALS. Two Volumes. By Sir H. Carpenter and J. M. Robertson. New York and London, Oxford University Press, 1939. 1,485 pages, illustrated, 10 by 6 inches, cloth, $35.00. Presents an account of the industrially important metals and alloys from the point of view of the relations between treatment, characteristics, and properties. Part one describes the characteristics of pure metals; their microstructure, crystal structure, and their behavior when subjected to the action of force. Part two is devoted to the theory of alloys. Part three deals with the mechanical properties of metals and their alteration by solution and corrosion. Part four discusses the influence of treatment on these characteristics and properties. Parts five and six deal specifically with the industrially important ferrous and nonferrous metals and alloys.

INTRODUCTION TO VECTOR ANALYSIS FOR PHYSICISTS AND ENGINEERS. By B. Hague. New York, Chemical Publishing Company, 1939. 118 pages, diagrams, 7 by 4 inches, cloth, $1.50. This monograph is intended to provide workers approaching the subject for the first time with an introduction to those elementary principles most used by physicists and engineers. A physical rather than a mathematical point of view is adopted in the explanations.

SPANNUNGSMESSUNG AN WERKSTÜCKEN. (Ergebnisse der Technischen Röntgenkunde, Bd. 6, edited by J. Eggert and E. Schiebold.) By E. Schiebold. Leipzig, Akademische Verlagsgesellschaft, 1938. 216 pages, illustrated, 9 by 6 inches, cloth, 18.80 rm. Discusses various questions involved in the investigation and measurement of stresses in metals by X-ray and optical methods, and outlines the use of these as practical test methods.

FINDING LIST FOR UNITED STATES PATENT, DESIGN, TRADE-MARK, REISSUE, LABEL, PRINT, AND PLANT PATENT NUMBERS. By M. Randall and E. B. Watson. Berkeley, Calif., University of California Press, 1938. 31 pages, 9 by 5 inches, paper, $0.35. This pamphlet is a handy guide to the location of any patent or trade-mark. The various series of official publications in which these have appeared are listed and the numbers of the patents, etc., in each volume are stated. A list of indexes is also included.

ELECTRODE POTENTIAL BEHAVIOUR OF CORRODING METALS IN AQUEOUS SOLUTIONS. By O. Gatty and E. C. R. Spooner. Oxford, England, Clarendon Press; New York, Oxford University Press, 1938. 504 pages, charts, etc., 9 by 6 inches, cloth, $8.00. Ten papers describing experiments. The first gives a general account of the principles underlying the theory of electrode potentials and indicates how they can be applied to individual cases. The remaining papers consider the specific behavior of mercury, silver, lead, copper, iron, antimony, cadmium, and magnesium, and deal in less detail with the behavior of several other metals.

ELECTRICAL ENGINEERING. Volume I. By W. T. Maccall. London, University Tutorial Press, 1938. 547 pages, illustrated, 9 by 6 inches, cloth, 15s. The first of two volumes, based on the author's "Continuous Current Electrical Engineering" and "Alternating Current Electrical Engineering," and intended to provide a textbook for engineering colleges.

A.S.T.M. STANDARDS ON ELECTRICAL INSULATING MATERIALS. Prepared by Committee D-9 on Electrical Insulating Materials. January 1939. Philadelphia, American Society for Testing Materials, 1939. 301 pages, illustrated, 9 by 6 inches, paper, $2.00. This pamphlet contains, in addition to the current report of the committee on electrical insulating materials, the methods for testing these materials which the society has developed. Eight standard and 19 tentative methods are described. Specifications for certain rubber and textile products and methods of testing shellac are also included.

CIRCUITS AND MACHINES IN ELECTRICAL ENGINEERING. By J. O. Kraehenbuehl and M. A. Faucett. New York, John Wiley and Sons, 1939. 601 pages, illustrated, 9 by 6 inches, cloth, $4.50. For the use of nonelectrical engineering students; both alternating and direct current are treated. The development of the theory of electrical circuits and the construction and operation of electrical machines are so presented as to enable the student to recognize and use the fundamental principles.

LOCOMOTIVE CYCLOPEDIA OF AMERICAN PRACTICE. Compiled and edited by the Association of American Railroads, Mechanical Division. Tenth edition. New York, Simmons-Boardman Publishing Corporation, 1938, 1,232 pages, illustrated, 12 by 9 inches, paper, $5.00. This edition contains improvements in arrangement and indexing, and has been thoroughly revised and brought up to date by the inclusion of new designs. The section on locomotive shops and engine terminals has been entirely rewritten.

PSYCHOLOGY FOR BUSINESS AND INDUSTRY. By H. Moore. New York and London, McGraw-Hill Book Company, 1939. 527 pages, illustrated, 9 by 6 inches, cloth, $4.00. Discusses the contribution of psychology to the solution of practical business problems. Selection of employes, testing fitness, training and promoting workers, accident prevention, fatigue, and psychological problems in advertising and selling are considered, and constructive suggestions made.

GMELINS HANDBUCH DER ANORGANISCHEN CHEMIE. System-Nummer 59: Eisen, Teil D, Magnetische und elektrische Eigenschaften der legierten Werkstoffe. Edited by Deutsche Chemische Gesellschaft. Eighth edition. Berlin, Verlag Chemie, 1936. 466 pages, illustrated, 10 by 7 inches, paper, 57.75 rm. A summary of the literature on the magnetic and electrical properties of the alloys of iron which appeared before September 1936. All the periodical literature is reviewed, with references to sources. Appended are lists of patented alloys and trade names of alloys with special properties.

A HISTORY OF SCIENCE, TECHNOLOGY AND PHILOSOPHY IN THE EIGHTEENTH CENTURY. By A. Wolf. New York, Macmillan Company, 1939. 814 pages, illustrated, 10 by 6 inches, cloth, $8.00. In this volume Doctor Wolf continues his previous work by giving a full, profusely illustrated account of the progress made during the eighteenth century in all the sciences and in technology. Of special interest to the engineer are the descriptions of advances in the testing of materials, the development of structural, road, and canal building, power plant and machinery, mining, metallurgy, etc. The illustrations are from contemporary works.

DEPRECIATION, PRINCIPLES, AND APPLICATIONS. By E. A. Saliers. Third edition. New York, Ronald Press Company, 1939. 482 pages, charts, etc., 9 by 6 inches, cloth, $5.00. Considers business management, corporation finance, and accounting in their connection with depreciation and valuation, including actual methods of procedure. Problems are analyzed and the practical and legal aspects of various methods of treatment discussed. Appendix contains tables of probable useful life and depreciation rates for hundreds of items.

ALTERNATING-CURRENT CIRCUITS. By J. M. Bryant, J. A. Correll, and E. W. Johnson. Third edition. New York and London, McGraw-Hill Book Company, 1939. 522 pages diagrams, charts, tables, 9 by 6 inches, cloth, $4.50. The first six chapters of this revised edition discuss the theory of alternating-current circuits and the development of the equations applying to the various types of circuits. The remaining ten chapters consider the application of these principles to polyphase circuits and transmission lines. Transients and circuits containing magnetic materials are not treated in this volume. Problems accompany each chapter.

DIRECT-CURRENT MACHINERY. By H. S. Bull. New York, John Wiley and Sons, 1939. 318 pages, illustrated, 9 by 6 inches, cloth, $3.00. Topics in this textbook have been arranged for better correlation with laboratory instruction; otherwise the treatment is that customary to elementary books on the subject. A set of explanatory problems is included.

L'ÉLECTROCHIMIE ET L'ÉLECTROMÉTALLURGIE, two volumes. By A. Levasseur. Fourth edition, enlarged. Paris, Dunod, 1939. Diagrams, etc., 10 by 7 inches. Volume I, Electrolyse. 210 pages, paper, 55 frs.; bound, 72 frs. Volume II, Fours Électriques. 254 pages, paper, 58 frs.; bound, 78 frs. Volume I discusses electrolytic theory and the general principles of electrolysis in solutions, describes specific processes for alkalis and chlorine compounds, and treats briefly of copper refining and the electrodeposition of metals. Volume II covers the general principles, calculations, installation methods, automatic regulation, efficiency, and specific applications of electric furnaces.

ELECTROLYTIC CONDENSERS, THEIR PROPERTIES, DESIGN AND PRACTICAL USES. By P. R. Coursey. New York, John F. Rider, 1938. 172 pages, illustrated, 9 by 6 inches, cloth, $3.00. Although somewhat restricted for commercial reasons, the most recent developments in electrolytic capacitors are presented in this book. The special properties, general and specific design information, and industrial applications are discussed with reference to the wet, semi-dry, and dry types of capacitors.

FUNDAMENTALS OF ELECTRICITY AND MAGNETISM. By L. B. Loeb. Second edition. New York, John Wiley and Sons, 1938. 554 pages, diagrams, etc., 9 by 6 inches, cloth, $4.00. Intended for students who have studied elementary physics and the elements of calculus, this textbook covers the general field of electricity and magnetism, emphasizing the mathematical approach to the subject, and is planned to enable the student to apply his physics to practical engineering problems. A survey of the historical development of the subject is included. The new edition has been revised and in part rewritten.

GEORG SIMON OHM. By R. von Füchtbauer. Berlin, VDI-Verlag, 1939. 246 pages, illustrated, 9 by 6 inches, cardboard, 7.50 rm. This biography of the great electrical physicist by his grandnephew, appears at the sesquicentennial of his birth. It contains a comprehensive account of his ancestry, life, and achievements, based upon family records and other material. A bibliography of Ohm's publications and a list of sources are included.

POWER-FACTOR ECONOMICS. By P. L. Rogers. New York, John Wiley and Sons, 1939. 143 pages, illustrated, 9 by 6 inches, cloth $2.50. Aims to answer the questions that arise when power factor is considered and to provide simple, accurate means for solving power-factor problems. Largely devoted to industrial plants, the book includes a section on the distribution systems of public utilities.

PRACTICAL HEAT. Edited by T. Croft, revised by R. B. Purdy. Second edition. New York and London, McGraw-Hill Book Company, 1939. 726 pages, illustrated, 8 by 6 inches, cloth, $5.00. A textbook on heat which can be used by those with no mathematical equipment beyond arithmetic. Explanation of the fundamental laws of heat phenomena, the effects of heat, and the properties of vapors, is followed by sections on the practical applications of heat phenomena in steam and internal-combustion power plants, building heating, and refrigeration.

THE PRINCIPLES of ELECTROCHEMISTRY. By D. A. MacInnes. New York, Reinhold Publishing Corporation, 1939. 478 pages, diagrams, etc., 9 by 6 inches, cloth, $6.00. With the object of presenting theoretical electrochemistry as it is today, as a logical, connected whole. This textbook attempts to deduce equations from first principles, to utilize the best experimental work in deriving values for physical constants, and to cite the original literature adequately.

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☐ 38-43	Lightning Arrester Subcom.	*Testing and Application of Lightning Arresters
☐ 38-99	Monroe	†Electrification of the San Francisco-Oakland Bay Bridge Railway
☐ 38-100	Whelchel	*Trends in Electrical Equipment in Hydraulic Power Plants
☐ 38-101	McMillan	*Polarity Limits of the Sphere Gap
☐ 38-102	Smith	*Use of Bismuth Bridge Magnetic Fluxmeter for A-C Fields
☐ 38-103	Shuck	*A Variable-Register-Ratio Watt-Hour Meter
☐ 38-104	Thomson	*Similitude of Critical Conditions in Ferroresonant Circuits
☐ 38-105	Morris	*Application of Copper-Oxide Rectifiers
☐ 38-106	Wagner	*Self-Excitation of Induction Motors
☐ 38-107	Ager	*Determination of Induction-Motor Performance
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☐ 38-111	Cozzens	*Insulation and Lightning Protection
☐ 38-112	Laughlin	*Carrier-Current Equipment
☐ 38-114	Skellett	*Narrow-Band Transmission System for Animated Line Images
☐ 38-115	Norwine	*Controlling Amplitude Characteristics of Telephone Signals
☐ 38-116	Gaylord	*The Pumping System of the Colorado River Aqueduct
☐ 38-117	Skilling	*The Electrical Strength of Air at High Pressure
☐ 38-118	Pierce and Hamilton	*Phase-Angle Control of System Interconnections
☐ 38-119	Lyon	*The Electrostatic Unbalance of Transmission Lines

Papers Presented at Southern District Meeting, Miami, Fla., November 28–30, 1938

☐ 38-124	Kirkwood	Grading the Engineer's Job
☐ 38-125	Almond	Electrical Design of Pickwick Landing Project
☐ 38-126	Jones	Mulsifyre System for Extinguishing Oil Fires
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☐ 38-128	Stratton & Stratton	Shop Practice in the Repair of High-Voltage Bushings
☐ 38-129	George & Bessesen	*Generator Damper Windings at Wilson Dam

Papers Presented at Winter Convention, New York, N. Y., January 23–27, 1939

☐ 38-122	Putman & Dann	Loading Transformers by Copper Temperature
☐ 39-4	Morgan, Brown & Schumer	Determination of Stray Load Loss in Induction Machines
☐ 39-5	Potter	Measurement of Temperature in Squirrel-Cage Induction Motors
☐ 39-6	Hellmund	The Rating of Electrical Machinery and Apparatus
☐ 39-8	Brown & Cahoon	An Amplifier-Wattmeter for Measurement of Watts and Vars
☐ 39-11	McDonald	Voltage Control of Mercury-Arc Rectifiers
☐ 39-13	Johnson	Predetermination of Temperatures in Resistance Welds
☐ 39-15	Relay Subcommittee	High-Speed Relaying Experience and Practise
☐ 39-17	Lynn	Effects of Temperature on Rotating Electrical Machinery
☐ 39-18	Rutherford	The Rating and Application of Motors for Refrigeration
☐ 39-19	AIEE & EEI Committees	*Bus Protection
☐ 39-21	Konn & Craton	*Performance of the 3600-Hp New Haven Electric Locomotives
☐ 39-22	Kotterman	The Magnesium Copper Sulphide Rectifier Battery Charger
☐ 39-23	Selctzky & Zucker	Sensitivity of the Four-Arm Bridge
☐ 39-26	Strang & Hanna	Modernization of Switch House Design
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* These papers have been published in the Transactions section of Electrical Engineering.
† This paper has been published in the 1938 AIEE Transactions volume.

Transactions

Papers and Discussions Comprising Pages 179–242 of the 1939 Volume

Crossbar Dial Telephone Switching System

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IT IS the purpose of this paper to describe briefly the crossbar dial-telephone central-office switching system which has recently been developed by the Bell System for use in large cities. Sixteen years ago, in February 1923, a paper was read before the Institute, by E. B. Craft, L. F. Morehouse, and H. P. Charlesworth of the Bell System, which outlined the history and the problems involved in telephone central-office switching and described the panel dial central-office system which had just been developed and was being introduced in the large cities. The first central office of this type was placed in service in December 1921, and since that time 456 panel dial offices serving nearly $4^1/_2$ million subscriber stations have been installed in 26 different cities throughout the country. During these years many improvements have been made in the panel system to make it more serviceable to the telephone public and to meet the new problems which have arisen, but in addition, the engineers of the Bell System have continued their search to find new and better means for meeting telephone switching demands. This work has resulted in the adoption of the crossbar-type central-office switching equipment. Two offices of this type were placed in successful operation during 1938 and others are in process of manufacture and installation.

It will be appreciated that for large metropolitan areas, the development and economic introduction of a central-office switching system which differs materially from the existing systems is a rather large undertaking. The system must fit into the existing plant as a whole without material change. Generally any important changes affecting the subscribers' use of the telephone or the methods used by switchboard operators should be avoided. Existing numbering plans should not be affected, existing classes of service should be continued, and the addition of others made feasible in case they should be required.

All of these and many other factors have been taken into account and all requirements have been met by the crossbar system which offers important improvements in telephone switching, both in operation and maintenance. Its introduction does not make any of the existing equipments obsolete in the sense that these equipments will be less serviceable nor will it cause their replacement. Central offices of the crossbar type can be installed in the same building with existing panel central offices without loss in operating economies in either type of office. Certain equipment, such as the existing and additional outgoing trunks to other central offices, manually operated switchboard positions, operating room and maintenance desks, power plant and alarms, can be used in common by the two types of offices in the same building.

General

Before describing the crossbar system it is desirable first to give a brief outline of the principal functions of a dial central-office equipment. Such an office is capable of serving 10,000 subscriber line numbers, and is provided with a sufficient number of connecting switches, trunks, and associated circuits so that under usual peak loads of traffic, calls will be completed promptly.

The central-office circuits, in response to the lifting of the receiver by the calling subscriber, connect the subscriber line to the switching equipment. This equipment then extends the calling line, "link by link," through several switching stages to the called line as determined by the called office code and line number dialed by the calling subscriber. When the connection has been established to the called line, the subscriber bell is rung and when the subscriber answers, the talking connection is completed. During the conversational period the connection is held under control of the calling telephone, and when the telephone receivers are replaced, the central-office equipment and the telephones are released for use on other calls. The equipment, of course, transmits the busy-tone signal to the calling subscriber if the called line is found busy, and automatically routes a call for a discontinued or an unassigned line to an operator who informs the subscriber of the status of such a line.

Operators and associated switchboards are provided in the dial system to handle certain classes of calls and to render assistance to subscribers when required. Calls to these operators are established in response to the dialing of operators' codes in a manner similar to the establishment of calls to other subscribers.

Operators are usually provided to complete calls terminating in a dial office which are originated by subscribers served by manual offices.

Prior to the introduction of the crossbar system, the Bell System employed two general types of dial central offices. These are the well-known step-by-step and panel systems.

The step-by-step system has been used generally in the smaller cities which are frequently served by a single central office or by a relatively small number of offices and where the trunking problems are consequently less complicated. The switches of the step-by-step system are controlled directly by the impulses from the subscriber dials and, necessarily in conformity with the dial, the system operates on a decimal basis. The selectors of this system are first moved under control of the dial to any one of ten vertical positions, corresponding to the numeral of the digit dialed, and in the case of trunk hunting switches, is then automatically rotated over a row of ten trunk terminals to find an idle trunk during the interdigital time of the dial.

The step-by-step switch thus has access to ten different groups of trunk terminals with ten terminals each. The location of the trunk groups on the switches is governed by the digits dialed and consequently the relocation of a

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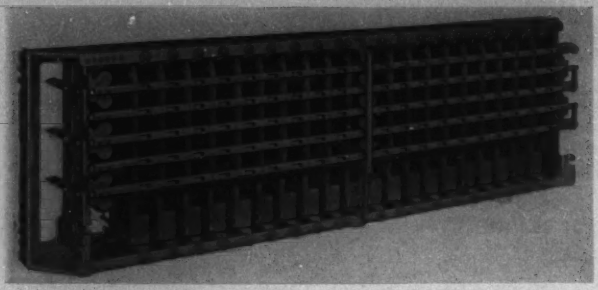


Figure 1. Crossbar switch—front view

group necessitates directory changes. These limitations in trunk access and flexibility are not material handicaps in the smaller cities throughout the country where the system is giving excellent service.

The panel system meets the complex service requirements of the larger cities with their large volume of traffic and multiplicity of central offices. In these cities the number of trunk groups is large and the number of trunks in the groups varies widely. Further, the number of groups and their sizes are frequently changed by the introduction of new offices and changes in the character or extent of existing central-office areas.

In the panel system, senders are provided which record and store the dial pulses as they are dialed and then independently control the operation of the switching units. The large panel-type switches provide access to large groups of trunks and to a large number of groups, and at the same time permit considerable variation in the sizes of the groups. The necessary flexibility in the size and location of the trunk groups is obtained by flexibly wired routing equipment provided in decoder circuits which are associated with the senders. These facilities permit trunk group locations on the switches as dictated by traffic regardless of the office codes listed in the directories and dialed by the subscribers. The panel system also readily provides for the routing of calls through intermediate or tandem offices where the traffic between offices can be more economically handled in this manner.

The crossbar system also makes use of the sender and decoder method of operation and provides a still greater flexibility in the trunking arrangements than is obtained by the panel system.

The Crossbar System

The two outstanding features of the crossbar system are the "crossbar switch" which is used for all major switching operations, and the "marker" system of control which is used in the establishment of all connections throughout the crossbar office.

The crossbar system is essentially a relay system employing simple forms of relays and relay-type structures for all switching operations. The apparatus consists almost wholly of crossbar switches, multicontact relays, and the usual small relays similar to those generally employed in all telephone systems. The switching circuits are wired to the contacting springs of the switches, and the connections through the switches are made by pressing contacts together by means of simple electromagnetic structures instead of the moving brushes and associated fixed bank terminals of other systems.

The use of relay-type apparatus with its small, pressure-type contact surfaces economically permits the use of twin or double contacts with thin layers of precious metal for all contact points. Obviously, double precious metal contacts make for reliable operation, especially with the low speech and signaling currents inherent to a telephone system.

The short mechanical movements and the inherently small operating time intervals of the "relay-like" crossbar switch permits the use of common circuits or "markers" to control the operation of the switches. This has permitted the use of large assemblies of switches and associated relays on unit frames which can be wired and completely tested for operation in the factory before the units are shipped.

In the design of the switching frames and associated control circuits, one of the objectives realized has been the standardization of a relatively small number of different types of equipment units, thereby simplifying manufacture and merchandising. This also simplifies the engineering of the equipment by the telephone companies in the preparation of their specifications to meet the particular traffic requirements of the various central offices.

The marker system used for controlling the switching operations has many advantages, the more important of which will be disclosed later in the general description of the operation of the equipment. It might be mentioned here, however, that the marker is an equipment unit consisting almost entirely of relays, which completes its functional operations in the establishment of a call in a fraction of a second. This short operating time permits a few markers to handle the entire traffic in the largest office. The markers are connected momentarily by means of multicontact relays to the various switching units of the office to control the establishment of the calls through the crossbar switches.

An outstanding advantage of the marker system of control is the "second-trial" feature, by means of which two or more attempts can be made to establish a call over alternate switches and trunks when the normally used paths are all busy. The markers are arranged to detect short-circuited, crossed, grounded, and open-circuit conditions at all vital points, and before releasing from a connection they make circuit checks to insure that the connection has been properly established. When trouble conditions are detected, they make a second attempt to complete the connection, after sounding an alarm and recording the location and nature of the trouble encountered. The marker system facilitates the introduction of new service features and changes in operation, which may be found desirable from time to time, due to the fact that the principal controlling features of the entire system are vested in a small number of markers.

Apparatus

Crossbar Switch

The crossbar switch from which the system derives its name is the basic switching unit of the system. Figure 1 shows the front view of a 200-point crossbar switch.

Fundamentally this switch consists of three major functional parts: (*a*) 20 separate vertical circuit paths, (*b*) 10 separate horizontal circuit paths, and (*c*) a mechanical means for connecting any one of the 20 vertical circuit paths to any one of the 10 horizontal circuit paths by the operation of electromagnets. From

a structural viewpoint the switch is comprised of a rectangular welded frame on which are mounted 20 vertical units and the selecting mechanism consisting of 5 horizontal bars operated by 10 selecting magnets.

Primarily the switch is a multiple relay structure with 20 vertical relay-like units, each unit having an operating or "holding" magnet and ten sets of contacts in a vertical row. The switch arrangement provides a rectangular field of contacts in 20 vertical rows and 10 horizontal rows or a total of 200 sets of contacts, one set at each "crosspoint." These crosspoint contacts are operated independently of each other by a coordinate operation of the horizontal and vertical bars. The horizontal bars are controlled by the 10 horizontal or "selecting" magnets and the vertical bars by 20 vertical or "holding" magnets. Any set of contacts in any vertical row may be operated by first operating the selecting magnet corresponding to the horizontal row in which the set of contacts is located, and then by operating the holding magnet associated with the vertical row. Since the contacts are held operated by the holding magnet alone, the selecting magnet is operated but momentarily and is released as soon as the holding magnet is operated. After the selecting magnet is released, other connections may be established through the switch by the operation of other selecting and holding magnets. It is thus apparent that ten connections can be established through the switch, one for each of the horizontal paths.

From figure 2 the rather simple mechanical interlocking of the horizontal and vertical bars which causes the operation of a set of crosspoint contacts will be understood. The ten sets of contacts in a vertical row are associated with the vertical or "holding" bar of the row. Each horizontal or "selecting" bar is provided with 20 selecting fingers which are made of flexible wire. These fingers are mounted at right angles to the bar, one at each of the vertical rows of contacts. Thus when a selecting bar is rotated through a small arc by its magnet, the selecting fingers will move up or down into a position so that when a holding bar is operated by its magnet, it will engage the selecting finger at the crosspoint of the two bars and cause the corresponding set of contacts to operate. The selecting bar and the fingers not used will then be released when the selecting magnet is released, but the selecting finger used to operate the selected set of crosspoint contacts will remain latched and the contacts held closed by the holding bar until the holding magnet is released at the end of the connection. The selecting fingers are each provided with a damping spring to reduce vibration on the operation and release of the fingers.

It will be noted that the selection operation is performed by five horizontal bars although there are ten horizontal rows of contacts. This is accomplished by operating the bars in either of two directions. As shown in figure 1, two magnets are associated with each bar, one whose armature is on top of the bar, the operation of which causes the selecting fingers to move in a downward direction, and the other whose armature is below the bar causing the fingers to move upward. The selecting bars are restored to the normal or mid-position by the centering springs located on the end of the switch adjacent to the magnets.

Figure 3 shows the vertical unit of the crossbar switch with its ten sets of normally open "make" type contact springs, the holding magnet at the bottom, and the long vertical armature to which is attached the vertical holding bar. The vertical unit shown has six pairs of contacts at each of its ten crosspoints. Other vertical units are provided with ten sets of three, four, and five pairs of contacts per set. One spring of each pair as shown is a fixed spring consisting of a projection of an insulated vertical metal strip, made in the shape of a comb. This strip extends from the top to the bottom set of contacts of a vertical row. Wiring lugs are provided at the lower end of these vertical strips facing the rear to which are wired the lines or trunks of the vertical circuit paths. At the lower end of these strips and facing the front is another projection used by the maintenance force for testing purposes. The mate or movable spring of each pair is individually insulated from all other springs. These springs extend to the rear of the switch for wiring purposes and may be strapped horizontally to the

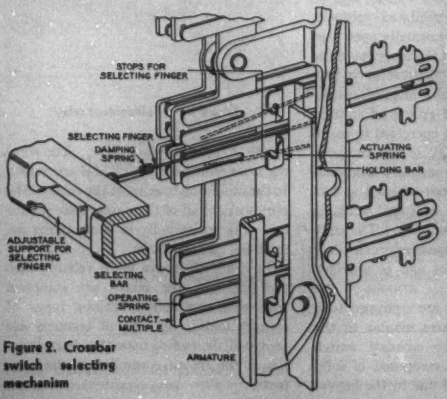


Figure 2. Crossbar switch selecting mechanism

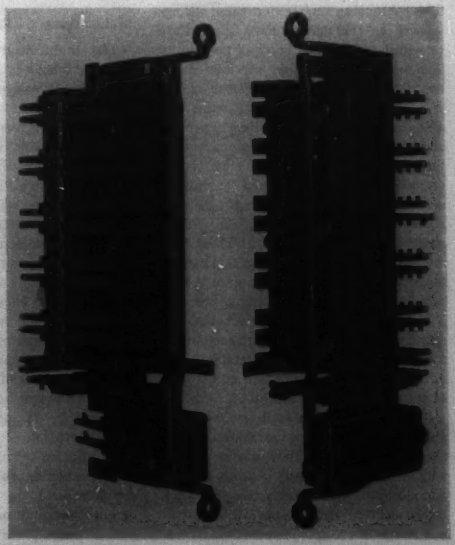


Figure 3. Crossbar switch vertical unit

Figure 4. Crossbar switch—rear view

corresponding springs of adjoining vertical units to extend the horizontal circuit path through the switch.

The contacting ends of the thin movable contacting springs are bifurcated to provide two flexible contacts in parallel. The contacting surfaces on these springs as well as the mating fixed springs are provided with a thin layer of palladium. The use of the double precious metal contacts is an important feature of the crossbar system in providing more reliable contacting surfaces. Experience has shown that the chance of simultaneous failures of both contacts of a pair is extremely small. The actual contacting surfaces of each pair of springs consist of small bars of contact metal located at right angles to each other. These bars are composed of a ribbon of nickel capped with a thin layer of palladium. This crossbar arrangement of contacts provides a rather large area over which the two springs can make contact with each other, and thereby permits considerable tolerance in the manufacture and adjustment of the contact spring assemblies.

The switch may be equipped with "off normal" contact spring assemblies. When these are furnished they are associated with each selecting or holding magnet and are operated like relay contacts when the associated magnet operates, regardless of which crosspoint contact is closed. They are used to perform circuit functions as required in the various uses of the switch.

In the design of the switch special attention was given to the problem of wiring and cabling. Figure 4 shows the wiring terminals on the rear of the switch. These terminals are arranged for individual wiring and also have staggered, notched projections so that the terminals can be readily strapped together horizontally with bare wire as shown. This is an important feature of the switch since it permits a multiple of terminals to be easily soldered together and reduces the wire congestion on the switch.

The 200-point crossbar switch is $9^1/_4$ inches in height and $30^1/_2$ inches in length. In addition a 100-point switch $20^1/_2$ inches in length is provided. This switch is similar to the 200-point switch but is equipped with ten vertical units.

Multicontact Relay

The multicontact relay used in the crossbar system is shown in figure 5. It resembles in design the vertical unit of a crossbar switch. The relay is provided in four sizes in respect to the number of contacts, namely, in 30, 40, 50, and 60 sets of individually insulated contacts, all of which are of the normally open type which are closed when the magnets of the relay are operated. Each relay is provided with two separate magnets, armatures, and associated groups of springs, and both magnets are energized in parallel in order to close all of the contacts. By operating the two magnets independently the structures can be used as two separate relays, each equipped with 15, 20, 25, or 30 sets of contacts. The relay occupies a mounting space approximately 2 inches by 11 inches and is provided with a cover.

All contact springs are equipped with twin contacting surfaces similar to the contacts used on the crossbar switch except that they are composed of solid bars of precious metal due to the heavy-duty requirements. To facilitate wiring, these relays are manufactured with two types of wiring terminals. In one type the movable springs are of graduated lengths and are provided with notched lugs for bare wire strapping to permit the multipling of springs horizontally to corresponding springs on other relays mounted adjacent. In the second type the strapping lugs are omitted and all springs are of the same length and are provided with soldering eyelets for individual or nonmultiple wiring.

The multicontact relay finds its chief use in the common connector circuits where a large number of leads must be connected simultaneously to a common circuit.

U- and Y-Type Relays

New and improved general-purpose small relays which have been coded the *U* and *Y* type are used in this system. Figure 6 shows a typical *U*-type relay. Although somewhat similar to the *E*- and *R*-type relays which have been in common use in the telephone systems for many years, it differs from them principally in that it has a heavier and more efficient magnetic structure which permits the use of a greater number of contact springs. These relays permit the use of spring assemblies up to a maximum of 24 springs in various combinations of springs, including transfer contacts and simple make and break contacts. The relays are constructed of relatively simple parts, most of which are blanked and formed in the desired shapes in the same manner as the

Figure 5. Multicontact relay

earlier *E*- and *R*-type relays. The cores are made from round stock and are welded to the mounting bracket of the relay. The structures of all of these relays are similar and differ principally in their spring assemblies and windings.

In order to insure more reliable contact closures, the relays are equipped with twin contacts. Various types of contact metal and sizes of contacts are provided, depending upon the characteristics of the circuit controlled by the contacts.

Improved methods of clamping the springs in their assemblies, together with the design of the springs, provide stability and minimize manufacturing and maintenance adjusting effort.

Contacts practically free from chatter on both the operation and release of the

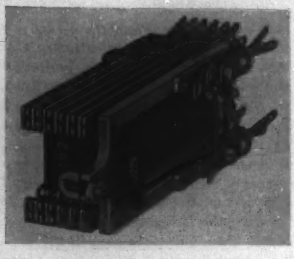


Figure 6. U-type relay

relay have been obtained by the use of relatively heavy stationary springs, short thin movable springs, and a pivoted arrangement of the armature suspension. By reference to figure 6 it will be seen that the rear ends of the armature are pivoted by two pins which project through holes in the hinge bracket mounted on the rear spring assembly. In the earlier flat-type relays of the *E* and *R* type, the armature was suspended at the rear by means of a reed-type armature hinge.

The *Y*-type relays make use of the same manufacturing tools and processes as the *U* type. Copper or aluminum sleeves are provided over the cores beneath the windings to secure the slow release characteristics required on these relays. The relay armature is embossed so that when the relay is operated, satisfactory contact is made between the metal surfaces of the magnetic circuit which insures uniform time characteristics.

In both the *U*- and *Y*-type relays the cylindrical cores permit the use of form-wound coils which are wound on special machines and slipped over the cores when completed. In the manufacture of these coils a removable mandrel is used. It is covered with a layer of sheet cellulose acetate and accommodates several coils. These coils are then automatically wound on the mandrel from different spools of insulated wire. Separations are left between adjacent coils so that when the winding operation has been completed the individual coils can be separated. A very thin sheet of cellulose acetate is automatically interleaved between successive layers of wire to hold the wire in place and to provide insulation between layers. This general method of winding coils also is used for the magnets of the crossbar switches and multicontact relays.

Functions of the Equipment Units

The general operation of the system as a whole may be more easily understood by first describing the principal equipment units in the system and their functions before proceeding with a description of the operation of the circuits. A simplified block diagram of the principal equipment units of the system is shown in figure 7. It will be noted that in general there are three types of equipment units:

1. The transmission battery supply and supervisory circuits consisting of the "district junctors" and the "incoming trunks."
2. The crossbar-switch frames.
3. The common "control" circuits, the "senders," and the "markers."

The "district junctor" and the "incoming trunk" circuits are composed principally of small relays. The district junctors furnish the talking battery for the calling subscribers and supervise the originating end of connections. The incoming trunks control the ringing of the called subscriber bells, furnish talking battery for the called subscribers, and supervise the terminating end of connections.

The switch frames, which consist almost entirely of crossbar switches, provide the means for switching between the subscriber lines, the district junctors, and the incoming trunks. Switch frames also are used for switching the district junctors and the incoming trunks to the senders.

The "senders" consist principally of small relays and their functions are similar

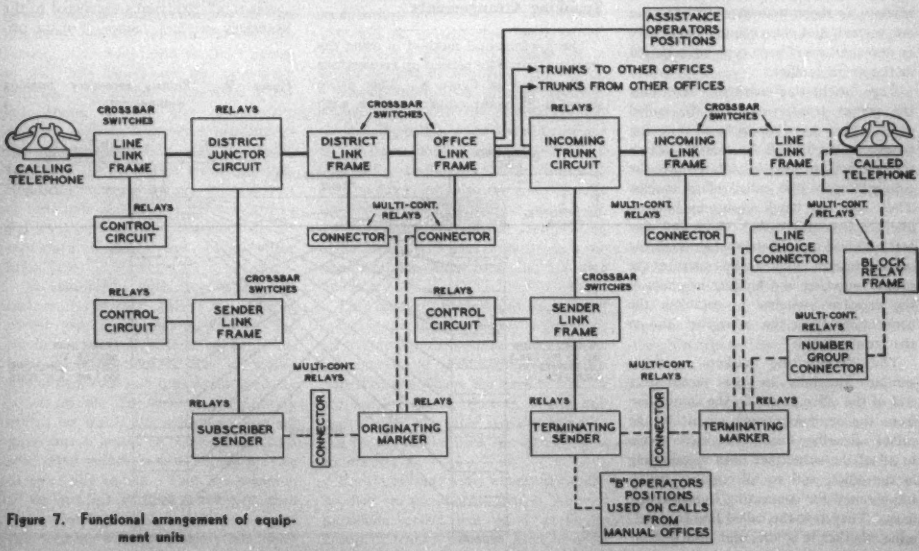


Figure 7. Functional arrangement of equipment units

to those of the operators at a manual switchboard. The "subscriber senders" register the called numbers from the subscriber dials and transmit the necessary information to the "markers," to the "terminating senders," and to the manual operator positions in manual offices for completing connections to the called lines.

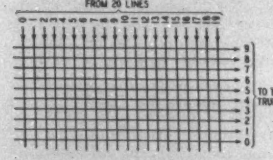


Figure 8. Simple trunking arrangement with a single 200-point crossbar switch

The subscriber senders also control the operation of the selectors in distant panel offices. The "terminating senders" in the terminating end of the crossbar office receive the numerical digits of the called numbers from the subscriber senders of any dial office and transmit the required information to the "terminating markers" for setting up the connections to the called lines.

The "markers" are the most important control circuits in the system. They are composed of both small and multicontact relays. There are two types, one for originating traffic and one for terminating traffic. The operating time of the markers is short, considerably less than one second, and consequently only three or four markers of each type are required in the average office.

The "originating markers" determine the proper trunk routes to the called office. They have access to all outgoing trunk circuits and all the crossbar-switch frames that are used for establishing the connections to the called office trunks. They test the trunk group to find an idle trunk to the called office, and also test and find an idle channel through the switch frames, and finally operate the proper selecting and holding magnets of the crossbar switches to establish the connections from the subscriber line to the trunk circuit.

The "terminating markers" perform similar functions in the terminating end of the office to set up the connection from the incoming trunk circuit to the called subscriber line. They have access to all of the subscriber lines terminating in the office, and to all crossbar-switch frames used for connecting to subscriber lines. They test the called line to determine whether it is idle, and also test for and find an idle channel through the switch frames and finally operate the proper magnets of the crossbar switches and establish the connection to the called subscriber line.

In addition there are common "control" circuits associated with the "line link" and the "sender link" frames for controlling the operation of the switches on these frames. There are also the common "connector" circuits, consisting mainly of multicontact relays, which are used for connecting the markers to the senders, to the switch frames, and to the test terminals of the called subscriber lines.

It should be noted that the line-link frames, although shown separately, are used for both originating and terminating traffic.

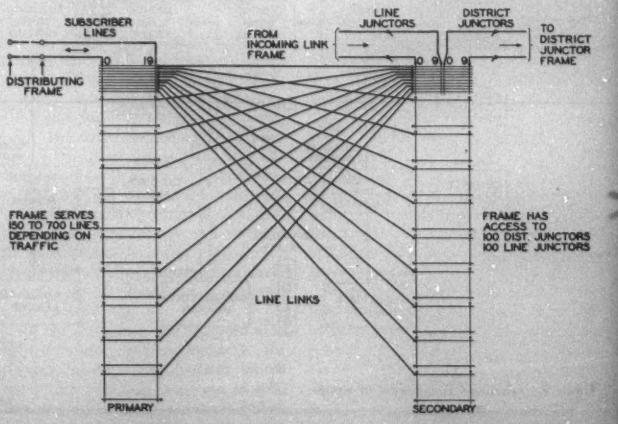
After the talking connection has been established between two subscribers, all of the common control units, such as the senders, markers, connectors, line-link control circuit, and the sender-link frames and their associated control circuits, will have been released, and the talking connection will be maintained in this condition by the holding magnets of the crossbar switches used on the line-link, district, office, and incoming-link switch frames. These switch magnets are held operated under control of the supervisory relays in the district junctor and the incoming trunk circuits and are released when the subscribers replace the receivers.

Trunking Arrangements

The fundamental method of using the crossbar switch for setting up connections is illustrated in figure 8. This figure shows a 200-point crossbar switch with 20 vertical units each wired to a subscriber line and ten trunks strapped horizontally across the switch. With such an arrangement, any one of the 20 lines may be connected to any one of the ten trunks. The number of lines which can be connected to the same ten trunks may be increased to 40 by adding a second 200-point crossbar switch with 20 different lines connected to its verticals and by wiring the horizontal contact multiple of this second switch to the horizontal multiple of the switch shown in figure 8. By adding other switches in this manner, any number of lines may be given access to the ten horizontal trunks.

To obtain greater trunking access, two groups of switches known as "primary" and "secondary" are used. Figure 9 illustrates this primary- and secondary-switch arrangement as used in the line-link switch frames and in various forms throughout the crossbar office. The switches are arranged in two vertical files of ten primary switches and ten secondary switches. There are 20 subscriber lines connected to the verticals of each of the ten primary switches and 20 trunk circuits are connected to the 20 verticals on each secondary switch. The horizontal multiples on the primary switches are connected to the horizontal terminals of the secondary switches, each primary switch having one horizontal path connected to each of the ten secondary switches. With this arrangement, the 20 lines of any primary switch have access to all 200 trunks connected to the secondary switches Since all of the pri-

Figure 9. Primary-secondary trunking arrangement



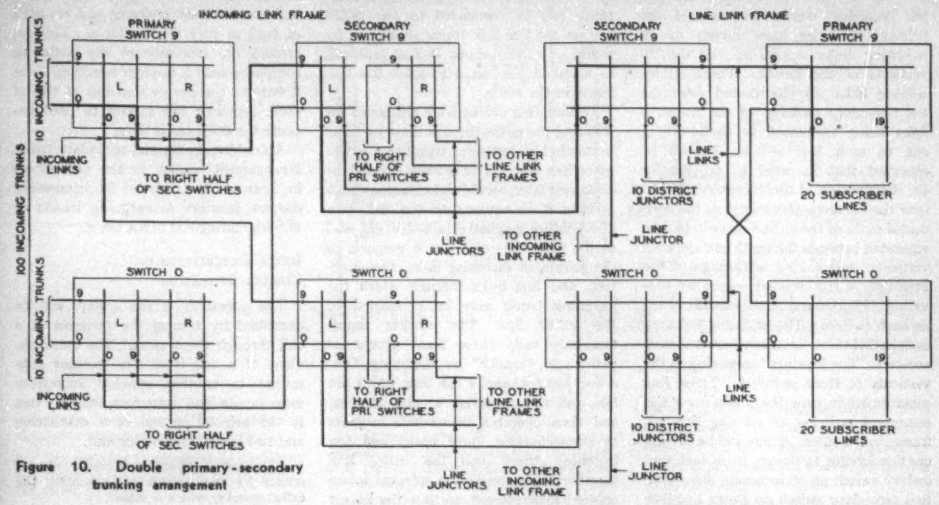


Figure 10. Double primary-secondary trunking arrangement

mary switches are wired in this manner, that is, with their ten horizontal paths distributed over the ten secondary switches, then all of the 200 lines on the primary switches have access to the 200 trunks on the secondary switches. It is evident that another vertical file of ten primary switches may be added with 20 subscriber lines connected to the verticals of each switch, and with the horizontal paths strapped and connected to the horizontal paths of the primary switches shown. This would give 400 lines access to the 200 trunks on the secondary switches. In actual practice on a line link frame, several files of primary switches may be connected together in this manner depending upon the traffic volume of the subscriber lines. The circuit paths connecting the horizontal rows of terminals of the primary switches to the horizontal rows of terminals of the secondary switches are called "line links."

To establish a path from a line circuit on a primary switch to a trunk circuit on a secondary switch, the common "control" circuit serving this line-link frame locates the subscriber line to be served and then simultaneously selects an idle "line link" on the primary switch on which the subscriber line appears and a group of trunks wired to a secondary switch in which there are one or more idle trunks. Thus the selection of the line link is made contingent upon the availability of trunks, and by means of this together with the primary-secondary distribution of the links a very efficient usage of the links and trunks is obtained.

In the line-link frame shown in figure 9, it will be seen that the trunks on the verticals of the secondary switches are split into groups of 100 trunks each, one group being connected to the "district junctors" and used for originating traffic and the other group of 100 trunks being connected to "line junctors" and used for terminating traffic.

It will be noticed that there is but one crossbar-switch appearance of a subscriber line in the office. This is on a vertical unit of a primary crossbar switch where both the originating and terminating calls are completed by means of the same line-link circuits. Thus all originating traffic from any of the 20 lines on any primary switch flows through the associated ten line links to the 100 district junctors and all terminating traffic to these 20 lines flows through the same ten line links from the 100 line junctors.

This single "primary and secondary" trunking arrangement also is used at other points in the system, such as in the originating and terminating sender-link switch frames, where the circuits reached are nondirectional, that is, where any one of the selectable circuits wired to the frame can be used for setting up a connection.

For the switch frames where the circuits reached are directional, that is, where a particular called line or a particular group of trunks must be used in order to complete a connection, the problem of trunking becomes more complex and it is necessary to provide a trunking arrangement using two "primary and secondary" switch frames arranged in tandem.

Figure 10 shows a typical arrangement of this kind which is necessary to secure the required trunking flexibility and efficiency. This figure shows an "incoming link" frame to which incoming trunks are connected and a "line link" frame to which subscriber lines are connected as described above. These two frames are used in tandem for establishing the terminating connections between the incoming trunks and the called subscriber lines. As is indicated, 100 incoming trunks are connected to the 100 horizontal paths of the ten incoming link frame primary switches, there being ten incoming trunks connected to each of the primary switches. A total of 150 to 700 subscriber lines may appear on the verticals of the primary switches of the line-link frame; however, only 200 lines or 20 on the verticals of each of the ten primary switches are shown in the figure.

In order to connect a particular incoming trunk to a particular called line, an idle channel is selected through these two switch frames, consisting of an "incoming link" on the incoming-link frame, a "line junctor" between the two frames, and a "line link" on the line-link frame, and all are connected in series as shown in the figure. It will be noted that

the incoming trunks on each of the primary switches have access to 20 incoming links appearing on the 20 verticals of the switch. These 20 incoming links are distributed over the ten secondary switches of the frame, 2 links being connected to each switch, one to each half switch. It will be observed that in order to provide for the distribution of the 20 incoming links over the ten secondary switches, the horizontal paths of the secondary switches are separated between the tenth and eleventh verticals, thus taking advantage of the flexibility of the crossbar switch by providing 20 horizontal paths instead of ten on each switch. The incoming links, on each half of these secondary switches, have access to "line junctors" appearing on the verticals of these switches. These line junctors are in turn distributed over the secondary switches of all the line-link frames in the office. There will be at least one line junctor as shown, from each secondary switch on an incoming link frame to a secondary switch on every line-link frame in the office, or a minimum of ten line-junctor paths between any incoming-link frame and any line-link frame. The number of the line junctors between these frames will vary depending upon the number of frames required in an office. The line junctors on the verticals of each of the line-link frame secondary switches in turn have access to ten line links on the horizontal paths. These ten line links are, as described above, distributed over the primary switches of the line-link frame, one to each primary switch. These line links then have access to the called subscriber lines which appear on the verticals of the primary switches. With this arrangement of switches and the three groups of interconnecting link paths, any incoming trunk can be connected to any called line on the line-link frame shown, or by means of other groups of line junctors, to a called line on any other line-link frame in the office.

Terminating markers are employed for selecting the paths through these switches to connect an incoming trunk to a called subscriber line. The marker, as will be explained later, records information which permits it to connect to the test wire and holding magnet of a called line and to the test wires and switch magnets of the groups of incoming links, line junctors, and line links through which the incoming trunk may be connected to the called line. The marker simultaneously tests these three groups of paths and "marks" an incoming link, a line junctor, and a line link which are idle and are accessible to one another, and then operates the switch magnets to connect these three paths and the incoming trunk and the called line together. The paths are selected in an ordered arrangement, so that the lowest numbered incoming links, line junctors, and line links are preferred and are used as long as they are available. This increases the efficiency of the paths as compared with a random selection, since it reduces the chance that one or two of them although idle cannot be used because the third one is busy.

A double primary and secondary trunk arrangement similar to the one shown in figure 10 is employed for connecting district junctors to outgoing trunks in the originating end of the office.

Brief Description of Circuit Operation

The operation of the system will be described by tracing the progress of a call through the system. The establishment of a call from one crossbar subscriber to another crossbar subscriber may be divided into four stages: two in the originating end of a connection and two in the terminating end.

1. The calling subscriber is connected to a sender for the purpose of registering the called number which is dialed.

2. The subscriber sender is connected to

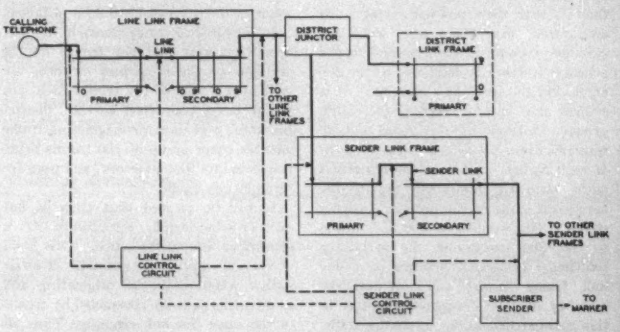


Figure 11 (above). Calling line connected to district junctor and subscriber sender

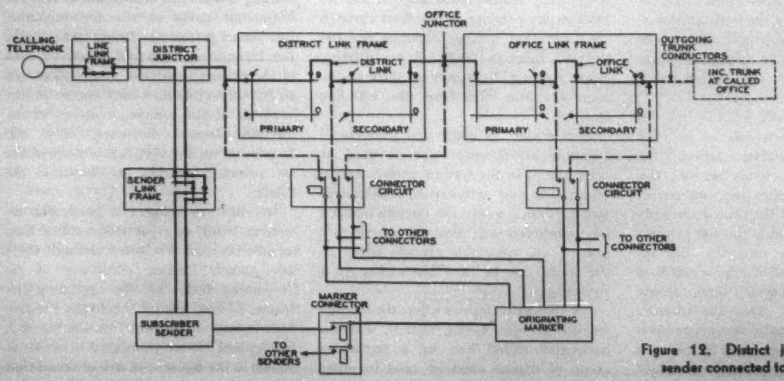


Figure 12. District junctor and subscriber sender connected to the outgoing trunk

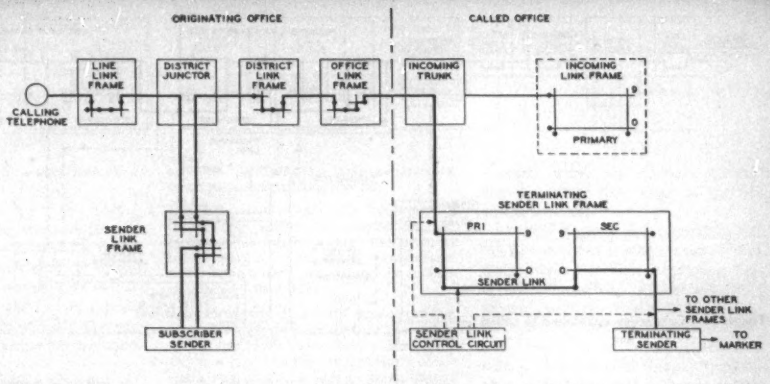


Figure 13. Connection established to terminating sender

an originating marker and the marker selects the switch frames for establishing the connection to an outgoing trunk.

3. The outgoing trunk circuit is connected to a sender in the terminating end to register the called number.

4. The terminating sender is connected to a terminating marker and the marker selects the switch frames for establishing the connection to the called subscriber line.

The first stage in the progress of a call is illustrated in figure 11. It will be seen that the line of a calling subscriber terminates on a vertical unit of a primary crossbar switch located on a line-link switch frame. When the subscriber receiver is lifted from the telephone preparatory to dialing, a line relay is operated, as in other systems, and the circuits proceed with the establishment of the connection to an idle subscriber sender which will register the called number when it is dialed.

The circuit functions on this stage of the call are as follows:

1. The subscriber line is located by the "line link control" circuit which is common to the line link frame, by a co-ordinate method of testing. That is, the control circuit determines the primary crossbar switch in which the line is located and the particular vertical unit in the switch on which the line is terminated. This operation is similar to the line-finder operation in other dial systems, except that the operation is accomplished by relay operations instead of by a mechanically traveling brush.

2. The line-link control circuit then simultaneously selects an idle line link between the primary switch in which the line appears, and a secondary switch on which a group of district junctors appears which has at least one idle district junctor in the group and which has access to idle senders and an idle sender link.

3. This will bring into operation the common "sender link control" circuit of the sender-link switch frame to which the selected group of district junctors is connected. This control circuit will select an idle district junctor in this group which appears on a primary switch on the sender-link frame. There are ten sender links serving the selected district junctor. These ten sender links and the ten sender groups to which they have access on the secondary switches are then tested simultaneously to find an idle sender link with access to a group of senders in which there are one or more idle senders. When this choice has been made an idle sender in the group is then selected.

4. The two control circuits in co-operation with each other operate, first the selecting magnets and then the holding magnets associated with the paths selected on the switches of both the line-link and sender-link frames, and thereby establish the connection from the calling subscriber to an idle subscriber sender.

This connection may be traced by referring to figure 11, from the calling line on the vertical unit on a primary switch of the line-link frame, through a line link and a secondary switch, through a district junctor circuit, to a vertical unit on a primary switch of the sender-link frame, through a sender link and a secondary switch to a subscriber sender which is connected to a horizontal circuit path on the secondary switch.

5. The two control circuits are then released and made available for use on other calls. The connections through the switches to the sender are held established by means of the holding magnets which are held operated over a signal control lead, called the "sleeve" lead, under control of the relays in the sender, which in turn are under control of the subscriber telephone.

Upon completion of these operations which take but a fraction of a second the subscriber sender transmits the dial tone to the calling subscriber as an indication to dial the number. When the subscriber dials, electrical impulses are transmitted to the sender, which receives and registers them. When the sender has registered the office code, which in New York City for example is contained in the first three digits dialed, the sender will connect itself to an idle originating marker by means of multicontact relays of a marker connector circuit.

Before proceeding further it is desirable to mention several other functions of the two common control circuits used for setting up this part of the connection.

1. The control circuits signal to the sender the class of the calling line, that is, for example, whether the line is a coin line or a noncoin line.

2. The sender-link control circuit signals to the sender the number of the district-link switch frame on which the selected district junctor appears, since this identification will be used later in the establishment of the connection.

3. The sender-link control circuit tests the circuit paths chosen from the line circuit to the sender before disconnecting from the connection, in order to insure the proper establishment of the connection. In case of a failure the control circuits will make repeated trials to establish the connection over different paths and give an alarm to the maintenance force.

4. Emergency control circuits are provided for use in case the regular control circuits are removed from service for maintenance reasons.

The next stage in the progress of the call is illustrated in figure 12. In this stage of the call the principal control unit is the originating marker. Its major function is to control the switches in the establishment of the connection to an idle outgoing trunk circuit to the called office, which may terminate in a distant office or in the same office as the calling subscriber.

When the subscriber sender connects to the originating marker through the connector circuit, the sender transfers the called-office code indication and the district link frame identification to the

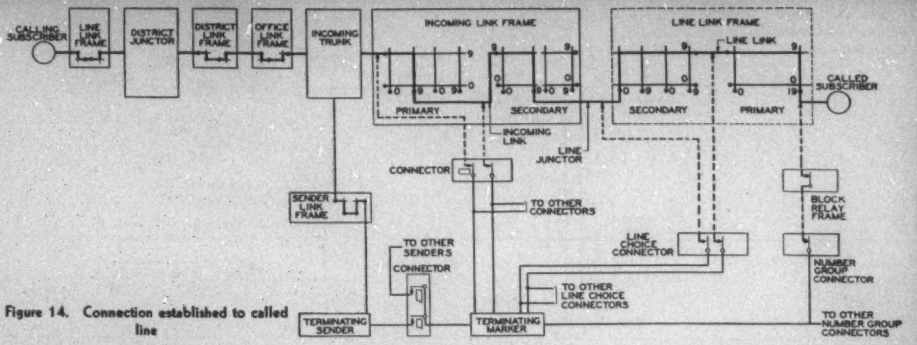


Figure 14. Connection established to called line

marker circuit. The called-office code indication causes the operation of a "route" relay in the marker corresponding to the particular office called.

There are a number of route relays in each marker and one is assigned to each called office routing. The route relay is connected as required by the office code to which it is assigned, so that it will direct the marker to the trunks of the called office and to the office-link switch frame on which these trunks appear and indicate the number of trunks in the group. The route relay also is connected to determine the type of the called office, such as crossbar, panel, or manual, and to set up the corresponding circuit conditions in the subscriber sender to enable the sender to handle the connection properly after the marker has been released. The connections of the route-relay contacts to the control relays in the marker are made flexible so as to permit the assignment of any route relay to any office code and to permit changes to be made from time to time in the route information, changes in trunk group sizes and location, changes in the type of terminating office, etc. The route relays and associated flexible connection facilities represent a considerable portion of the marker equipment, especially in large metropolitan offices where several hundred central offices are involved.

When the route relay is operated, the marker proceeds with the establishment of the connection as follows:

1. It connects to the office-link frame on which the trunks to the called office appear. This connection is made through the office-link frame connector circuit, one of which is provided for each office-link frame. Through this connector the marker is extended to the test leads of any desired trunk group on the office-link frame and to the crossbar switches of the frame. When so connected the marker has exclusive control of the trunks and switches of the frame and other markers which desire connection to the same frame are deprived of access until the connected marker releases.

2. The marker next tests the outgoing trunks to the called office and selects an idle one. If, as determined from the route relay, the trunks are divided over more than one frame, the marker will connect to the second group of trunks on the second office-link frame in case the first group of trunks is found to be busy.

3. The marker also connects by means of a connector circuit to the district-link frame associated with the district junctor to which the calling line is connected. The identification of this frame was obtained from the sender and the sender-link control circuit as previously mentioned. Through the connector circuit of the district-link frame the marker is extended to the control leads of the district junctor circuit and the crossbar switches of the district-link frame. As in the case of the office-link frame, only one marker is connected to a frame at a time.

4. The marker after selecting an idle trunk circuit which appears in a horizontal circuit path on one of the secondary switches of the office-link frame, then proceeds with the selection of an idle channel through the switches of the two switch frames. A number of these connecting channels is provided between the district junctor and the outgoing trunk. Each channel consists of a "district link" on the district-link frame, of an "office link" on the office-link frame, and an "office junctor" connecting the district-link frame to the office-link frame. The marker tests a group of these channels simultaneously and selects an idle one. It then operates the switch magnets which will connect these three paths of a channel, and the district junctor and the outgoing trunk together, thereby establishing a connection from the district junctor to the outgoing trunk.

5. When the marker has completed this operation it checks the connection to insure that it has been properly established and that it is capable of being held under control of the district junctor, before releasing itself from the connection.

6. The marker performs these functions in approximately 0.5 second then releases and becomes available for use on other calls.

It will be observed that the three links involved in establishing the connections between the district junctors and the outgoing trunks are used in series and are chosen simultaneously. Generally in other systems the establishment of a connection involving three such paths, is made in three successive stages with a possibility that after a selection has been made at one stage it will be found that the paths accessible to it are all busy and, therefore, the connection cannot be completed.

Before describing the next stage in the establishment of a call, it is desirable to point out other features and functions of the originating marker.

1. The marker permits wide variations in the sizes of trunk groups, permitting trunk groups as small as two and as large groups as may be required. This makes for an efficient use of the office-link frame terminals and thereby tends to reduce the office-link frame equipment.

2. The marker makes a second trial to establish connections over alternate trunk routes in case calls cannot be completed over the normally used groups because of busy conditions.

3. The marker makes a continuity test of the circuits over which the switches are controlled and tests them for short circuits, crosses, and open and grounded circuits which would interfere with the proper establishment of a call and where troubles are detected, it signals this condition to a common "trouble indicator" where an indication of the trouble and its location is recorded and a maintenance alarm given. The call is then completed over another group of circuits.

The first stage in the progress of the call through the terminating end of a crossbar office is illustrated in figure 13. It consists of connecting the incoming end of the selected trunk to a terminating sender for the purpose of receiving the number of the called line from the subscriber sender.

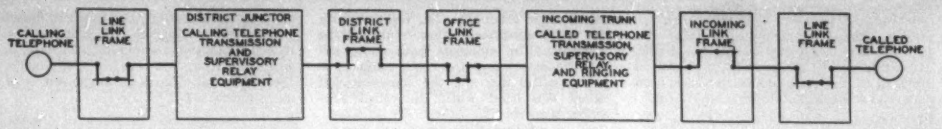


Figure 15. Completed talking connection

When the incoming trunk is selected by the originating end of the office equipment, the "sender link control" circuit associated with the terminating sender-link frame on which the incoming trunk appears, is called into action. The control circuit then proceeds with the following functions:

1. To locate the incoming trunk circuit, which appears on one of the ten horizontal paths of a primary switch.

2. It selects an idle sender link between this primary switch and a secondary switch on which there is an idle terminating sender.

3. The control circuit selects one of the idle terminating senders reached through the secondary switch and then operates the selecting and holding magnets associated with the selected circuits, which will establish the connection from the incoming trunk to the terminating sender.

4. The control circuit will signal to the terminating sender the number of the incoming-link frame in which the incoming trunk appears. This frame identification will be used later in establishing the connection to the called line.

5. The control circuit will then disconnect after checking to insure that the connection to the sender has been properly established and that it will be held under control of the trunk and sender circuits after the control circuit leaves the connection.

As soon as this operation has been completed, which takes but a fraction of a second, the terminating sender will be in direct connection with the subscriber sender in the originating end of the connection. This path may be traced, by referring to figure 13, from the subscriber sender through the sender-link frame, through the district junctor, through the district-link and office-link frames, over the outgoing trunk to the incoming trunk, and through the terminating sender-link frame to the terminating sender.

At this stage of the connection the calling subscriber is still connected with the subscriber sender, and dialing may be still in progress. As the subscriber proceeds with the dialing of the digits of the called number, the subscriber sender will transfer them to the terminating sender. This is done by means of impulses transmitted over the circuit paths between the two senders. When the subscriber sender has completed the transfer of the called number to the terminating sender, the subscriber sender will be released and the calling line will then be connected through the district junctor to the incoming trunk.

When the terminating sender has secured the record of the called line number, the sender then connects to an idle terminating marker by means of multicontact relays of a connector circuit.

The next stage in the progress of the call is shown in figure 14. The terminating marker is the principal control unit at this point in the connection. Its principal function is to provide means for establishing the connection from the incoming trunk to the called subscriber line.

When the terminating sender has connected to the terminating marker, the sender will transfer both the called line number and the incoming-link frame identification to the marker. The terminating marker then proceeds to establish the connection to the called line as follows:

1. It connects itself to the particular "number group connector" circuit including the "block relay" frame in which the called line appears in its numerical sequence. All subscriber lines are provided with a set of three test terminals which appear on the block-relay frame. These terminals correspond to the directory number of the subscriber line. A number group connector generally has access to the test terminals of several hundred line numbers depending on the terminating traffic to the lines.

2. The marker will obtain a connection through the number group connector to the busy-test terminal of the particular called line and determine whether the line is busy or idle.

3. It will determine from the two other test terminals, the identification of the

Figure 16. Line-link frame

line-link frame where the called line appears, and the horizontal group of line links which has access to the called line. In addition, it determines the type of ringing to be applied to the called line from the circuit conditions on the test terminal.

4. Assuming that the called line is idle, the marker will connect, through the line-choice connector circuit, to the line-link frame and to the ten line links which have access to the called line.

5. It will then connect, through the connector circuit, to the incoming-link frame associated with the incoming trunk to which the calling subscriber line is now connected. The incoming-link frame identification was obtained from the sender-link control circuit through the sender as previously mentioned.

6. The marker will then select an idle channel through the incoming-link and line-link frames as previously described. This channel will consist of an "incoming link," a "line junctor," and a "line link" all to be connected in series. The marker then operates the proper selecting and holding magnets of the crossbar switches in each frame which establishes the connection from the incoming trunk to the called subscriber line.

7. The marker will then cause the incoming trunk to start the proper ringing over the called subscriber line and to transmit the ringing-tone signal over the trunk to the calling subscriber.

8. At this point the terminating marker and the terminating sender will have completed their functions and, together with the terminating sender-link frame, will be released. The complete connection will then be established from the calling line to the called line and the conversational circuit completed when the called subscriber answers.

If the terminating marker finds the called line busy it will cause the incoming trunk circuit to transmit a busy tone to the called subscriber.

The terminating marker has the following other important functions:

1. If the call is for a private branch exchange (*PBX*) the condition on one of the test terminals of the called line in the number group connector will inform the marker that the line is one of a group of lines. The marker will test all of the lines in the group, testing up to as many as 20 simultaneously, and will select an idle one. The lines of a private branch exchange may be assigned to nonconsecutive numbers within the usual 10,000 series, and with the exception of the numbers dialed, they may be assigned to line numbers in a special group of 2,500 outside of the 10,000 series. These features reduce the necessity for number changes due to the growth of private branch exchanges, and conserve subscriber line numbers in the office. The lines of a private branch exchange group can be distributed over several line-link frames and over two number-group connectors to equalize the terminating traffic load in the case of busy private branch exchanges.

2. The marker recognizes numbers dialed which are unassigned, disconnected, or changed numbers, and automatically routes such calls to an operator who will inform the calling subscribers as to the status of the numbers called.

3. In case the called number is on a party line, the marker determines from one of the test terminals which station of the line is to be rung, and signals the incoming trunk to provide the proper ringing.

4. The marker tests the continuity of the circuit paths to be used to the called line before establishing the connection, to insure that the connection is properly set up and that it will be held under control of the subscriber telephone after the marker disconnects. The marker also tests for short circuits, crosses, and grounds, and in case of a failure due to any inoperative condition it will connect itself to the common trouble indicator and leave a record of the trouble and its location and give an alarm to the maintenance force.

Figure 15 shows the complete talking connection through the various trunks and switch frames as finally established after all of the common control circuits have been released.

On a call to a subscriber served by a panel dial office, the connection is

Figure 17. Three frame assembly of district-junctor, district-link, and sender-link frames

Figure 18. Sender frames

routed through the district-link and the office-link frames in the same manner as on a call terminating in a crossbar office, but in this case the idle trunk chosen on the office-link frame terminates in an incoming panel switch in the distant panel dial office. The subscriber sender of the crossbar office causes the incoming and final selectors in the terminating panel office to select the called subscriber line without the aid of any terminating senders in either office. When the subscriber sender has completed these functions it will be released and the connection will be established from the calling line over the interoffice trunk circuit and through the terminating panel incoming and final selectors to the called line. On this type of call the subscriber sender operates in the same manner as though the called line were in a crossbar office, and the selectors in the panel office operate in the same manner as though the call had originated in another panel office. No changes are required in the panel selectors to function with the crossbar office.

On a call for a subscriber in a manual office, the call would be routed through the switches of the district-link and the office-link frames as previously described and connected to a trunk circuit on the office-link frame which terminates in the *B* switchboard in the manual office. The subscriber sender of the crossbar office then transfers the called number by impulses transmitted over the interoffice trunk circuit to the operator's position equipment in the manual office. The called number appears in the form of visible numbers on the operator's keyshelf. The operator completes the connection by "plugging" the associated trunk circuit, which terminates on a cord and plug, into the called subscriber line jack.

A call originating in a panel dial office for a subscriber line in a crossbar office reaches the crossbar office through an incoming trunk circuit as in the case where the call originated in a crossbar office. The call from the panel office is then handled by the crossbar office terminating sender and marker in exactly the same manner as described for calls originating in the same crossbar office.

A call originating in a manual office for a line connected to the crossbar office reaches the crossbar office over an incoming trunk circuit from an *A* operator's position in the manual office. These incoming trunks in the crossbar office are similar to the incoming trunks previously described. In this case, however, the incoming trunk is connected to a terminating *B* sender and by means of this sender to a *B* board operator in the crossbar office. The *B* operator will obtain the called number verbally from the distant *A* operator and then, by means of the keyset on her position, register the called number in the terminating sender. The terminating sender will then select a terminating marker and the connection will be established in exactly the same manner as described for a call originating in a crossbar office.

Maintenance Facilities

Automatic routine testing circuits are provided for testing all the principal circuit units, such as the district junctors, incoming trunks, and senders. These test circuits automatically put each circuit, one after the other, through all of its functions on all classes of calls to insure that it performs satisfactorily. It tests the important relays of the circuits to insure that they have the proper adjustment to handle the worst circuit conditions. In case any circuit fails to meet the test conditions, the test is stopped and an alarm given to the maintenance force.

Trouble indicator circuits are provided for use in connection with the test and maintenance of the marker circuits. These circuits are arranged so that when trouble is encountered by a marker, the marker will seize the trouble indicator and operate combinations of relays and light small lamps which indicate the nature and the location of the failure and give an alarm to the maintenance force.

Figure 19. Originating marker frame

Equipment

Figure 16 shows a typical switch frame used in the crossbar system. This particular frame is a "line link" frame which serves a group of subscribers for both originating and terminating traffic. The frameworks on which the equipment is mounted are constructed of rolled bulb angle-iron sections with a sheet-metal base. The bulb angle construction provides a framework which is light in weight and has the required strength, and permits an equipment mounting arrangement which conserves space and facilitates the wiring of the apparatus. The frames are welded and incorporate such features as sanitary base construction, guards to protect the apparatus and wiring against damage from the rolling ladders located between the rows of frames, and a cable duct or runway for the a-c power service cables with plug receptacle outlets for use with electric soldering irons, portable lights, etc.

These frame equipments are built in standardized units, which provide the required flexibility to satisfy the variations in telephone traffic and classes of service encountered in the different telephone areas. Where it has been necessary to divide an equipment assembly into several units, due to the

limitations of handling, shipping, and to care for different classes of service, the equipments have been designed so that the installation effort required for interconnecting such units has been reduced to a minimum.

The bays of equipment located at the right, in figure 16, equipped with crossbar switches, are the primary line-link bays. The vertical units of these crossbar switches are wired to the subscriber lines. These primary bays are made available in units of 100 and 200 line capacities. As discussed previously the number of primary bays provided in a line-link frame may be varied to fit the traffic load of the subscriber lines. The left-hand bay of this frame contains the vertical file of crossbar switches, known as the secondary switches and the vertical units of these switches are wired to district junctors and line junctors. The line-link control circuit apparatus, which is common to the frame, is located at the bottom of this bay.

Figure 17 shows a group of three frame units, namely, the subscriber sender link, the district junctor, and the district-link frames, which are closely associated in the trunking network and have been designed as a fixed equipment group. However, for shipping reasons the group is divided into three separate equipment units. The district-junctor circuits, consisting primarily of relays, are mounted in groups on the middle frame. These groups are provided in standardized units of various types, such as those required to serve coin and noncoin subscriber lines. A similar arrangement of frames is used for the combination of terminating sender link, the incoming trunk, and the incoming-link frames.

Figure 18 shows a row of subscriber sender frames and a frame of *A* operator senders located at the extreme right. These frames accommodate five senders which may be of one type, or a combination of both types. The crossbar switch shown on the right of each subscriber sender unit, is a part of the sender circuit and is employed for the purpose of registering the called numbers dialed by the subscribers. The *A* operator senders are associated with the *A* operator switchboard equipment and are used for the completion of certain classes of calls such as toll and assistance calls.

A view of the originating marker frame is shown in figure 19. There will be a variation in the equipment on this frame for different cities due to the variation in the number of route relays required, the number depending upon the number of central-office codes that may be dialed by subscribers and operators. This variable feature is cared for by providing the route relay equipment in bays of 100 codes as shown in the right-hand bay. The terminal fields shown below the route relays on the frame provide the flexible connecting facilities which permit the use of any route relay for any office code and which readily permit changes in routings, variations in trunk group sizes, and other features which are subject to change from time to time.

Figure 20. Battery supply feeders, power wiring, fusing, etc.

The power-plant equipment provided for the crossbar offices is similar to the equipment now being furnished for all large dial central offices. The principal power supply arrangements provide 48-volt direct current for the operation of practically all the signaling and the telephone transmission circuits. Also several other sources of direct current are provided for miscellaneous purposes as in other standard dial systems. A new distribution scheme for the battery feeders on the frames is employed which reduces the amount of copper required. A common set of 48-volt battery feeders supplies the signaling and talking current for all frames. Individual frame filters are connected across the battery supply leads at the frames where a noise-free battery supply is required for talking circuits. Figure 20 shows a view of the overhead battery cables, conduits for the a-c power leads, and the fuse cabinets for the fusing of the battery supply to a row of frames.

Application

As mentioned in the first part of this paper, two crossbar dial central offices were cut into service in 1938 and these have now been in commercial operation for several months. One of these offices serves a residential area in Brooklyn, while the other serves a congested business area in the midtown Manhattan district of New York City. The operation of these offices under actual service conditions has been highly satisfactory and our expectations in regard to performance have been fully realized.

This type of system will be used for new offices in large cities instead of the panel system as rapidly as manufacturing and plant conditions permit and the apparatus which was designed for this system will be used in other fields of the telephone system.

Breakdown Studies in Compressed Gases

By ALVIN H. HOWELL
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THE superior dielectric strength of compressed gases, their low dielectric loss, their low dielectric constant, their low cost, and the fact that they are self-healing make them very promising insulating media. Compressed-gas insulation has been used in precision condensers where low dielectric loss is essential; it has been tried in other types of equipment such as transformers; it has been suggested for electric power cables where the low dielectric constant is of considerable importance; and recently it has found interesting and important application in the production of very high voltages by electrostatic means for use in X ray and nuclear physics work.

While several investigations of the insulating properties of compressed gases have been made, nearly all of them have dealt with small total voltages and were made under conditions very different from those that would obtain in a practical application. The present work outlines the scope of former studies, gives an introduction to the physics of breakdown in gases, and presents experimental data for gas pressures, principally air, up to 600 pounds per square inch and direct voltages up to 450,000 volts. The results have been analyzed in the light of existing theories, and new evidence is presented to support the modifications in theory that are suggested.

Experimental Aspects

Spark-over or breakdown between a pair of electrodes immersed in a gas will occur at a voltage which is, at ordinary temperatures, determined primarily by the gas pressure, the electrode separation, the electrode configuration, the nature of the gas, and the nature of the applied voltage, particularly its rate of increase. The effect of pressure and electrode separation on the sparking voltage is given by Paschen's law,* which states that for a given gas and a uniform field the sparking voltage is a function of the product of the electrode separation and the pressure; the more general similarity law holds for electrodes which give nonuniform fields.

The curve in figure 1 shows the relationship between the sparking voltage for air and the product of the pressure and the electrode separation. The minimum exhibited by the curve may be considered to separate the region of vacuum breakdown from that of pressure breakdown. It will be observed that no uniform air gap can have a sparking voltage less than 350 volts. In the region of pressure breakdown the sparking voltage rises steadily as the product of the pressure and the electrode separation is increased.

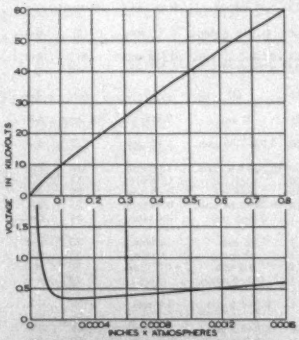

Figure 1. Breakdown voltages for air—the Paschen relationship (from Schumann[15])

Since pressures below atmospheric were used in the experiments which led to the formulation of Paschen's law, the curve in figure 1 has to be restricted with regard to pressure. The numerous tests which have been made at higher pressures, summarized in table I, have shown that data for pressures above a certain value, possibly ten atmospheres, cannot be represented by a single curve.

As figure 1 shows, large sparking voltages occur only when the product of pressure and electrode separation is large. Table I shows that in this region only a few measurements have been made, and they are for alternating voltages. The present work is aimed in the same direction but with direct potentials which, of course, permit a study of the effect of polarity.

With one exception the measurements presented in this paper have been made in air with gauge pressures up to 600 pounds per square inch and voltages up to a maximum of 450,000 volts. These studies have been made with uniform fields, needle point to plane, and concentric-cylinder electrode arrangements.

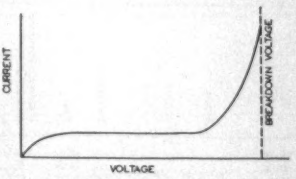

Figure 2. Current flow before the initial discharge

Uniform fields were used because they are of general interest and they permit a proper comparison with the results of others. The needle-point-to-plane arrangement was selected in order to determine the effect of pressure on the current-voltage characteristic of such points. This information is of interest to those operating Van de Graaff generators in compressed air. The cylindrical electrodes are also of general interest. Only cylindrical arrangements having a ratio of cylinder diameters approximately equal to ϵ were used. This ratio produces, for a given outside diameter of cylinder and a fixed voltage between cylinders, the smallest gradient at the surface of the inner conductor.

The current flowing through the gas prior to sparking was studied for the uniform fields and the cylinders as well as for the point-to-plane configuration. This feature of the work, measurement of current above atmospheric pressure, has not been reported by other workers in this field.

Theoretical Background

In order to introduce the theoretical side of the breakdown picture, let the current-voltage characteristic for a pair of plane electrodes be considered. Figure 2 shows that the current first rises in proportion to the voltage at low voltages, then reaches a constant or saturation value (perhaps 10^{-12} amperes with the equipment used in the present experi-

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* In reality W. S. Harris[14] discovered the Paschen relationship in 1834, more than a half century before Paschen's publication. This is the more remarkable because absolute potential measurements could not be made until 1860. Harris therefore states his results in terms of the charge on a condenser of fixed capacity; for this case charge and voltage are proportional.

ments and maximum pressure), and later increases rapidly as the breakdown voltage is approached. When this limiting voltage is reached a new equilibrium condition is set up which is determined by the experimental system, but which is characterized by much larger values of current. The new equilibrium condition may be a glow (or some related discharge such as a brush or corona) or it may be an arc. In cases where the glow appears first an arc will appear at a still higher voltage. In the discussion that follows the term initial discharge is used to designate the first discharge that appears, and the voltage at which this occurs is called the ignition voltage or the initial voltage. The term breakdown voltage is used synonymously with sparking voltage to designate the voltage at which the initial discharge transfers to an arc.

Table I. Index to Former Studies of Breakdown at Pressures Above Atmospheric

Name	Reference	Year	Maximum Pressure (Atmospheres)	Maximum Pressure for Maximum Spacing	Range of Spacing	Maximum Spacing for Maximum Pressure	Maximum Potential (Kilovolts)	Nature of Potential	Gas	Electrodes
Wolf	50	1889	5	5	1 mm.	1 mm.	19	d-c.	Air, O_2, N_2, CO_2	Spherical segments (10 cm. diameter)
Wolf	50	1889	9	9	1 mm.	1 mm.	19	d-c.	H_2	Spherical segments (10 cm. diameter)
Hemptinne	26	1902	60	60	(a)	(a)	5.6 max.	a-c.	N_2	Platinum wires (0.2 mm. diameter)
Hemptinne	26	1902	50	50	(a)	(a)	6.4 max.	a-c.	CO_2, O_2	Platinum wires (0.2 mm. diameter)
Hemptinne	26	1902	80	80	(a)	(a)	4.6 max.	a-c.	H_2	Platinum wires (0.2 mm. diameter)
Ryan	44	1904	100	100	0.156–0.25 in.	0.25 in.	50 max.	a-c.	Air	Sewing needles (point-point)
Ryan	44	1904	62	62	0.08 –0.25 in.	0.25 in.	58 max.	a-c.	CO_2	Sewing needles (point-point)
Ekern	6	1904	102	102	0.1–0.3 in.	0.3 in.	43 max.	a-c.	Air	Sewing needles (point-point)
Ekern	6	1904	42	42	0.2 in.	0.2 in.	50 max.	a-c.	Air	Various kinds of points
Ryan	42	1905	49	49	0.096 in.	0.096 in.	110 max.	a-c.	CO_2	Aluminum wires (0.09375 in. diameter) rounded ends
Guye and Guye	15	1905	86	86	~0.2 mm.	~0.2 mm.	19	d-c.	Air, N_2, O_2	Platinum wires (1 mm. diameter)
Guye and Guye	15	1905	63	63	~0.2 mm.	~0.2 mm.	12	d-c.	H_2	Platinum wires (1 mm. diameter)
Guye and Guye	15	1905	53	53	~0.2 mm.	~0.2 mm.	19	d-c.	CO_2	Platinum wires (1 mm. diameter)
Fessenden	10	1905	12	12	0.083 in.	0.083 in.	40 max.	a-c.	Air	Flat plate condenser. [First application of compressed gas.]
Cassuto and Occhialini	3	1907	102	1.6	0.1–6.3 mm.	0.1 mm.	(b)	d-c.	Air	Planes (4 cm. diameter)
Ceruti	4	1909	40	25	0.03–0.22 mm.	0.156 mm.	13.5	d-c.	Air	Gold plated spheres (15 mm. diameter)
Ceruti	4	1909	50	30	0.03–0.22 mm.	0.125 mm.	24.6	d-c.	Air	Platinum plated spheres (15 mm. diameter)
Watson	48	1909	15	15	(c)	(c)	(c)	d-c.	Air	Spheres (0.3175, 0.635, 2.54 cm. diameter)
Wien	49	1909	21	21	3 mm.	3 mm.	48 max.	a-c.	Air, CO_2	Condenser (5 concentric cylindrical plates)
Hayashi	25	1914	70	70	0.52–1.82 mm.	1.82 mm.	117	d-c.	Air, N_2	Magnesium spheres (1 cm. diameter)
Hayashi	25	1914	70	60	0.52–1.82 mm.	1.08 mm.	110	d-c.	CO_2	Magnesium spheres (1 cm. diameter)
Hayashi	25	1914	30	30	0.58 mm.	0.58 mm.	41	d-c.	N_2 and H_2 mixed	Gold spheres (1 cm. diameter)
Hayashi	25	1914	70	70	0.65 mm.	0.65 mm.	70	d-c.	(d)	Gold spheres (1 cm. diameter)
Guye and Stancescu	19	1917	53	16	0.34–2.24 mm.	0.34 mm.	35	d-c.	CO_2	Gold plates (14 mm. diameter)
Guye and Mercier	16	1920	26	4.1	0.5–5 mm.	0.5 mm.	54	d-c.	CO_2	Planes (45 mm. diameter)
Guye and Mercier	16	1920	4.1	4.1	5 mm.	5 mm.	53	d-c.	CO_2	Calottes (150 mm. radius of curvature)
Guye and Mercier	16	1920	23.1	23.1	1 mm.	1 mm.	52	d-c.	CO_2	Calottes (30 mm. radius of curvature)
Guye and Mercier	16	1920	34.9	34.9	0.5 mm.	0.5 mm.	43	d-c.	CO_2	Calottes (15 mm. radius of curvature)
Hammershaimb and Mercier	23	1921	1*	1	0.5–5 mm.	5 mm.	18	d-c.	N_2	13 sets of electrodes ranging from points to planes
Hammershaimb and Mercier	23	1921	4*	4	0.5–4.5 mm.	4.5 mm.	52	d-c.	N_2	9 sets of electrodes
Hammershaimb and Mercier	23	1921	10*	10	0.5–2.5 mm.	2.5 mm.	69	d-c.	N_2	8 sets of electrodes
Hammershaimb and Mercier	23	1921	50	1	0.5–5 mm.	0.5 mm.	69	d-c.	N_2	Spherical segments (15 mm. diameter)
Hammershaimb and Mercier	23	1921	55	1	0.5–5 mm.	0.5 mm.	75	d-c.	N_2	Planes (10 mm. diameter)
Hammershaimb and Mercier	23	1921	50	1	0.5–5 mm.	0.5 mm.	80	d-c.	N_2	Planes (45 mm. diameter)
Guye and Mercier	17	1922	51	5.5	0.5–5 mm.	0.5 mm.	62	d-c.	CO_2	Spherical segments (15 mm. diameter)
Hammershaimb	22	1923	50	10	0.5–2.5 mm.	0.5 mm.	80	d-c.	N_2	Spherical segments (15 mm. diameter)
Guye and Weigle	20	1923	22	22	0.5 mm.	0.5 mm.	24	d-c.	CO_2	Spherical segments (15 mm. diameter)
Guye and Weigle	20	1923	43	23	0.5–1 mm.	0.5 mm.	54	d-c.	CO_2	Spherical segments (15 mm. diameter)
Guye and Weigle	20	1923	38	20	0.5–1 mm.	0.5 mm.	60	d-c.	N_2	Spherical segments (15 mm. diameter)
Guye, Mercier, and Weigle	18	1925	40	5	0.5–5 mm.	0.5 mm.	56	d-c.	CO_2	Spherical segments (15 mm. diameter)
Palm	34	1926	15	15	2–8 mm.	8 mm.	220 max.	a-c.	N_2	Planes (108 mm. diameter)
Palm	34	1926	15	15	2–8 mm.	8 mm.	255 max.	a-c.	CO_2	Planes (108 mm. diameter)
Goodlet, Edwards, and Perry	14	1930	5	5	0–10 cm.	10 cm.	100 eff.	a-c.	Air	Rods ($1/_2$ in. diameter), rounded ends
Rehet	38	1931	26	2	1–15 mm.	2 mm.	110 eff.	a-c.	Air	Planes (about 5 to 8 in. diameter)
Rehet	38	1931	28	10	0.5–4 mm.	2 mm.	105 eff.	a-c.	Air	Spheres (16 mm. diameter)
Bölsterli	1	1931	17*	17	0–6 cm.	6 cm.	200 eff.	a-c.	N_2	Needle gap
Bölsterli	1	1931	20	20	3.2 mm.	3.2 mm.	60 eff.	a-c.	N_2, CO_2	Concentric cylinders (25.4 and 31.8 mm. diameter)
Bölsterli	1	1931	20	20	3.2 mm.	3.2 mm.	13 eff.	a-c.	He	Concentric cylinders (25.4 and 31.8 mm. diameter)
Zeier	51	1932	116	5	0.1–5 mm.	0.4 mm.	100	d-c.	Air	Spheres (15 mm. diameter)
Zeier	51	1932	48	5	0.2–5 mm.	0.6 mm.	80	d-c.	Air	Spherical segments (300 mm. diameter)
Zeier	51	1932	48	48	0.3–0.5 mm.	0.5 mm.	70	d-c.	Air	Sphere (2 mm. diameter)—segment (300 mm. diameter)

* = constant at value stated.

(a) Very small; not specified. (b) Arbitrary units. (c) Results show gradients as a function of pressure. (d) Air, N_2, O_2, CO_2, H_2, and illuminating gas.

To understand the behavior of the current it is necessary to know that normally cosmic rays, radioactive radiations, and photoelectric action are constantly producing ions and electrons in the gas, at the electrodes, and at the walls of the container if there are any. At low voltages the current is produced by the movement of these charge carriers, under the action of the electric field, to the electrodes. The saturation condition is reached when the charge carriers arrive at the electrodes at the same rate as that at which they are produced by the causes mentioned above, allowing of course for such effects as recombination. The current rises above the saturation value when the electric field is able to cause a multiplying of the charge carriers in the gas and at the electrodes. This multiplying action increases rapidly with

Table I (Continued). Index to Former Studies of Breakdown at Pressures Above Atmospheric

Name	Reference	Year	Maximum Pressure (Atmospheres)	Maximum Pressure for Maximum Spacing	Range of Spacing	Maximum Spacing for Maximum Pressure	Maximum Potential (Kilovolts)	Nature of Potential	Gas	Electrodes
Zeier	51	1932	116	5	0.2–4 mm.	0.6 mm.	80	d-c	N_2	Spheres (15 mm. diameter)
Zeier	51	1932	48			0.8 mm.	80	d-c	N_2	Spherical segments (300 mm. diameter)
Zeier	51	1932	29			1.2 mm.	80	d-c	N_2	Segment (300 mm. diameter)—plane
Zeier	51	1932	48	48	0.3–0.5 mm.	0.5 mm.	58	d-c	N_2	Sphere (2 mm. diameter)—segment (300 mm. diameter)
Zeier	51	1932	56.5	5	0.2–4 mm.	0.6 mm.	90	d-c	CO_2	Spheres (15 mm. diameter)
Zeier	51	1932	48				75	d-c	CO_2	Spherical segments (300 mm. diameter)
Zeier	51	1932	48	5	0.1–~3 mm.	0.6 mm.	70	d-c	CO_2	Spheres (2 mm. diameter)
Zeier	51	1932	39	39	0.5 mm.	0.5 mm.	58	d-c	Air and N_2 mixed	Spheres (15 mm. diameter)
Palm	33	1934	25	14	1–16 mm.	1 mm.	280 max	a-c	N_2	Planes (108 mm. diameter)
Palm	33	1934	23	18	1–8 mm.	1 mm.	290 max	a-c	CO_2	Planes (108 mm. diameter)
Palm	33	1934	10*	10	6.5 mm.	6.5 mm.	375 max	a-c	N_2	Concentric cylinders (38 and 51 mm. diameter)
Palm	33	1934	15.7*	15.7	18.5 mm.	18.5 mm.	445 max	a-c	N_2	Concentric cylinders (133 and 170 mm. diameter)
Palm	33	1934	14*	14	23.5 mm.	23.5 mm.	556 max	a-c	N_2	Concentric cylinders (150 and 197 mm. diameter)
Palm	33	1934	14*	14	6.4 mm.	6.4 mm.	228 max	a-c	N_2	Concentric cylinders (25.4 and 31.8 mm. diameter)
Goldman and Wul	12	1934	17	17	3–17.5 mm.	17.5 mm.	80 max	a-c	N_2	Point (platinum wire 0.435 mm. diameter)—plane
Goldman and Wul	12	1934	17	13	1–10 mm.	5 mm.	130	d-c	N_2	Negative point (platinum wire 0.435 mm. diameter)—plane
Goldman and Wul	12	1934	17	17	1–50 mm.	50 mm.	150	d-c	N_2	Positive point (platinum wire 0.435 mm. diameter)—plane
Goldman and Wul	12	1934	17	9	3.7–10 mm.	3.7 mm.	115	(e)	N_2	Positive point (platinum wire 0.435 mm. diameter)—plane
Goldman and Wul	12	1934	17	6	3.7–10 mm.	5 mm.	160	(e)	N_2	Negative point (platinum wire 0.435 mm. diameter)—plane
Goldman and Wul	13	1935	25	25	10 mm.	10 mm.	55	d-c	N_2	Positive point (platinum wire 0.435 mm. diameter)—plane
Goldman and Wul	13	1935	25	25	10 mm.	10 mm.	130	d-c	N_2	Negative point (platinum wire 0.435 mm. diameter)—plane
Goldman and Wul	13	1935	25	25	10 mm.	10 mm.	50 max	a-c	N_2	Point (platinum wire 0.435 mm. diameter)—plane
Goldman and Wul	13	1935	31	31	10 mm.	10 mm.	50 max	a-c	N_2	Point-plane. Temperature = 13°C.
Goldman and Wul	13	1935	31	31	10 mm.	10 mm.	36 max	a-c	N_2	Point-plane. Temperature = 100°C.
Goldman and Wul	13	1935	Up to 48		Up to 20 mm.		150	a-c and d-c	N_2	Various odd shapes (all unsymmetrical gaps)
Finkelmann	11	1937	20	~9	2–20 mm.	7 mm.	375 max	a-c	N_2	Brass plates (13.5 cm. diameter)
Finkelmann	11	1937	20	~7	1–20 mm.	7 mm.	375 max	a-c	CO_2	Brass plates (13.5 cm. diameter)
Finkelmann	11	1937	20	~8	1–20 mm.	7 mm.	400 max	a-c	Air	Brass plates (13.5 cm. diameter)
Finkelmann	11	1937	20	~14	1–20 mm.	10 mm.	380 max	a-c	H_2	Brass plates (13.5 cm. diameter)
Finkelmann	11	1937	19	19	9.35 mm.	9.35 mm.	250 max	a-c	Air, N_2, CO_2	Concentric cylinders (180 and 199.4 mm. diameter)
Finkelmann	11	1937	21	21	9.35 mm.	9.35 mm.	165 max	a-c	H_2	Concentric cylinders (180 and 199.4 mm. diameter)
Finkelmann	11	1937	11	11	19.3 mm.	19.3 mm.	370 max	a-c	Air, N_2, CO_2	Concentric cylinders (159.8 and 199.4 mm. diameter)
Finkelmann	11	1937	16	16	19.3 mm.	19.3 mm.	360 max	a-c	H_2	Concentric cylinders (159.8 and 199.4 mm. diameter)
Finkelmann	11	1937	8	8	29 mm.	29 mm.	380 max	a-c	Air, N_2, CO_2	Concentric cylinders (140.0 and 199.4 mm. diameter)
Finkelmann	11	1937	13	13	29 mm.	29 mm.	375 max	a-c	H_2	Concentric cylinders (140.0 and 199.4 mm. diameter)
Finkelmann	11	1937	6	6	39.7 mm.	39.7 mm.	375 max	a-c	Air, N_2, CO_2	Concentric cylinders (119.2 and 199.4 mm. diameter)
Finkelmann	11	1937	10	10	39.7 mm.	39.7 mm.	365 max	a-c	H_2	Concentric cylinders (119.2 and 199.4 mm. diameter)
Rodine and Herb	40	1937	5	3	2–10 mm.	5 mm.	100	d-c	(f)	Brass spheres (5 cm. diameter)
Hudson, Hoisington, and Royt	29	1937	7	7	3 mm.	3 mm.	150	d-c	(g)	Brass spheres (5 cm. diameter)
Hudson, Hoisington, and Royt	29	1937	7	7	3 mm.	3 mm.	98	d-c	(h)	Brass spheres (5 cm. diameter)

* = constant at value stated.
(e) Impulse. (f) Various mixtures of CCl_4 and air. (g) Various mixtures of CCl_2F_2 and air. (h) Various mixtures of SO_2 and air.

voltage at voltages just below the ignition value. At the ignition voltage the current ceases to depend on external sources of ionization; it becomes self-sustaining.

A complete analysis of the problem involves accurate knowledge about all the possible methods of producing charge carriers either at the electrodes or in the gas, about the manner in which these carriers are moved through the gas as a result of diffusion and the influence of the electric field, and finally about the manner in which they may disappear. At the present time it is recognized that new carriers may be produced by a number of methods, but adequate quantitative knowledge about most of these is not yet available.

Plausible ionization processes in the gas are: (1) ionization by electron impact; (2) ionization by positive-ion impact; (3) photoelectric action; (4) ionization by metastable atoms and excited atoms; (5) multistage ionization (all types); (6) ionization by neutral atoms; (7) thermal ionization.

The anode need not be considered because electrons coming from it would immediately return. The possibility of the emission of positive ions from the anode appears remote and, so far, is not supported by experiment.

Clearly the difficulty is not one of finding a conceivable process by which the charge carriers can be multiplied, but rather one of finding which of the many available ones are important. There is general agreement that the action of electrons in the gas is the important or primary process. This is the α process. It assumes that one electron produces α new ion pairs in traveling one centimeter through the gas. Now if an electron leaves the cathode, new ones will be generated in geometrical progression, giving rise to an electron avalanche; the number of electrons in the avalanche is $\epsilon^{\int_0^d \alpha dz}$ after the distance d to the anode has been traversed. Experimental tests have shown that the current rise just preceding the initial discharge cannot be accounted for by the α mechanism alone.

The β mechanism assumes that the positive ions ionize neutral gas molecules as they move to the cathode and that one ion in moving one centimeter produces β new ion pairs. On the assumption that only the α and β processes are active, an equation may be derived which is able to describe the current rise before the initial discharge. The equation furthermore predicts an infinite current for a certain combination of the variables α, β, and d, or for a certain combination of pressure, voltage, and electrode separation. The relationship of variables predicting unlimited current flow has been interpreted to be the condition necessary for the initial discharge, and has been found to be in agreement with experimental values. The self-sustaining current which accompanies the initial discharge is established when the ions produced by one electron are able to produce one electron.

An alternate possibility is the γ mechanism which assumes that the positive ions liberate electrons when they strike the cathode, and that γ electrons are emitted by each positive ion. This assumption with the α mechanism also allows the current before the initial discharge to be described and the ignition voltage to be predicted.

It happens that there are still other mechanisms which when taken with the α process will allow the predischarge current to be described and the initial voltage to be predicted. They are the action of photons in the gas or at the cathode, and the action of metastable atoms in the gas or at the cathode. The most generally accepted one is the η mechanism which assumes that photons liberate electrons from the cathode and that η electrons are liberated by each photon. Of course it is also possible to satisfy the current and voltage requirements with a combination of two or more of the secondary processes.

The multiple solution difficulty arises from the fact that, in all equations, α dictates the principal behavior of the current rise in that it governs exponentials whereas the other quantities play a less dominating role. The experimental data are not especially precise and do not permit a distinction to be made between the various equations.

From the standpoint of understanding the elementary physical processes that are at work, it is evident that little can be concluded from considering only the predischarge current rise and the initial voltage. Since it has already been mentioned that one of the features of the present work is the measurement of current above atmospheric pressure, it might at first seem that this is misdirected effort. However, the currents which can be described by the equations mentioned above are not the currents measured in this study; the currents measured here are self-sustaining values.

Additional information has been obtained from other sources, such as the time necessary to initiate the self-sustaining condition, photographs of the

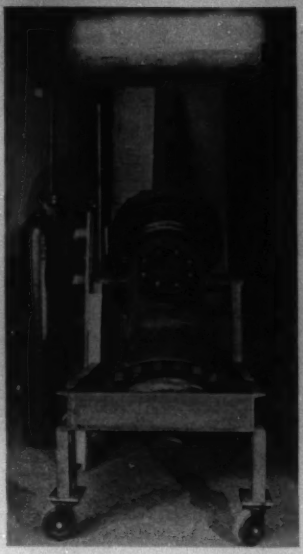

Figure 3. Pressure vessel and generator

early stages of breakdown, direct experiments which study the individual elementary processes, and the experience with all the various types of gas discharges. The evidence seems to indicate that many of the proposed mechanisms are either absent or that they are too rare to consider in the ordinary sparking phenomenon. At present it is believed that the important ones for the common gases are the α, γ, and η processes, with the additional consideration of field distortion due to space charge. For long sparks in mixed gases such as lightning strokes, or for self-sustaining discharges from isolated electrodes, it appears that photo-ionization in the gas becomes important as well. Here it seems necessary to have the electrons regenerated in the gas rather than at the electrodes, as they are with the γ and η processes.

To date the theory has been concerned principally with explaining breakdown at pressures which do not exceed atmospheric. At higher pressures one might expect to find new processes at work; a discussion of this possibility will be included with the results.

Apparatus

The experiments presented in this paper were made in a special portable pressure vessel having an internal diameter of 13 inches and an inside length of 42 inches.

The tank was fabricated by welding together standard outside diameter pipe and steam fittings. It had two hand holes near the center and each contained a window. The tank was so suspended on its portable truck that all the operations, including assembly, could be managed readily by one person. Figure 3 shows the complete vessel and the generator in the operating position.

The high direct potentials (up to one-half million volts) as obtained from a Van de Graaff generator, were introduced into the pressure chamber through a solid Textolite bushing which was forced into a tapered nozzle at the upper end of the tank. The bushing extended 15 inches into the container and 65 inches outside.

The electrodes used for producing uniform fields were turned from ordinary cold-rolled steel. They had a flat section 2 inches in diameter and edges formed by using a constantly decreasing radius of curvature. The maximum diameter of each electrode was $7\frac{1}{16}$ inches. Figure 4 shows a sectional view of the three types of electrodes that were used. Experience showed that the distribution of sparks over the flat area was uniform and that the sparks were practically all confined to this area. For this reason it was assumed that the electrodes produced a satisfactory uniform field.

The low-potential electrode was supplied with a ball and socket joint which permitted the electrodes to be made perfectly parallel at any time simply by forcing them together. This electrode was moved by a fine screw which allowed the electrode separation to be known to within 0.001 inch. The technique used eliminated back lash, and stretching of

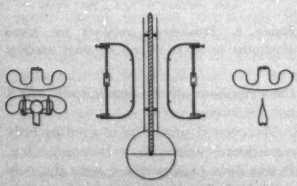

Figure 4. Electrode configurations: uniform field, concentric cylinder, point to plane

the tank was readily corrected for by adjusting the scale. An ordinary spark plug was used as a bushing for leading the current through the tank wall; the leads both inside and outside the tank were shielded.

The needle-point-to-plane configuration was realized by replacing the low-potential electrode of the system described above with a 30-degree cone having a phonograph needle set in its point.

Copper was used for making the cylindrical electrodes for constructional reasons. In each case the inner electrode was attached to the conductor running through the bushing and terminated in an aluminum sphere which insured that the highest gradient would occur in the test section. The outer cylinders were held between spun flanges which were at ground potential, the cylinder was insulated from the flanges. The whole system was held in position by four adjustable screws directed radially against the tank wall from each flange. This allowed the cylinders to be made perfectly concentric. Experience showed that the distribution of sparks within the length of the outer cylinder was perfectly uniform and the insulating feature made it possible to measure the current flow to the outer cylinder.

Four sets of cylindrical electrodes were employed and each of these had a ratio of diameters as nearly equal to e as it was possible to obtain them. The combinations of diameters used were $\frac{1}{2}$ inch and $1\frac{1}{16}$ inches; $\frac{3}{4}$ inch and $2\frac{1}{16}$ inches; $1\frac{1}{8}$ inches and 3 inches; and $1\frac{1}{2}$ inches and 4 inches. The outer cylinder was 5 inches long in all cases.

Gas was obtained in commercial tanks and was dried by passing it slowly through a five-foot tower filled with Drierite and then through phosphorus pentoxide. The moisture inevitably trapped in the vessel was removed by placing a container of phosphorus pentoxide in the tank and circulating the enclosed gas for a period of 10 or 12 hours. As the results will show, air was generally employed, though two tanks of nitrogen and one of helium were used in some special experiments.

The voltage measurements were made with a special resistor consisting of 960 10-megohm units connected in series and encased in a suitable Textolite container filled with insulating oil. A microammeter (accuracy one-half of one per cent) was used for measuring the resistor current. Numerous tests indicated that this voltage measuring system certainly gave an accuracy of two per cent, and probably of one per cent. The meter was used within a grounded case and was protected from surges by the usual system of a neon bulb and a suitable series resistance. The long lead to the resistor was completely shielded.

The current to the low-potential electrode was measured with a multiple-range semisuspension meter which was used in a grounded case with surge protection and shielded leads. Currents as small as 0.005 microampere were detectable with this instrument.

The pressure was measured with two Crosby steam gauges, one measuring pressures to 200 pounds and the other to 1,000 pounds.

The following simple and definite procedure was always followed in taking observations. The potential was increased in a step-wise fashion from a value definitely below the minimum voltage at which the gap would break down, until a spark was produced. The increments approximated one per cent or two per cent, and voltage was held constant for one minute at each step. The value at which breakdown occurred and also the current flowing just before breakdown were recorded. The procedure was repeated until about ten readings were available for averaging.

Although the technique employed is time consuming, it was felt that it produced the desired results. The readings of any one group sometimes differed from the average by as much as ten per cent, but the average was generally reproducible to within two to five per cent. The large amount of scattering occurred only at the higher pressures, where the time lag becomes excessively large; at low pressures, where the lag is small, the measurements can be taken a good deal faster and more accurately. Inasmuch as the breakdown generally consisted of a single spark, and this of short duration because of the small capacity of the generator, no trouble was experienced from the arc effect such as Reher[38] reports.

Some of the workers who have made measurements at high pressures have used ultraviolet radiation, X rays, or radioactive radiations on the cathode to cut down the time lag. Such devices were not used in this work as it was desired to study the currents existing normally without added sources of ionization.

Results

Uniform Field

The results for the uniform field may well be introduced by considering figures 5 and 6. The first of these shows values of breakdown voltage as a function of electrode separation for various constant pressures. Clearly the voltage increases almost linearly with the separation at any pressure. Figure 6 shows the values

38. For all numbered references, see list at end of paper.

of breakdown voltage as a function of pressure for various fixed separations. Here the voltage increases linearly with the pressure for the first eight or ten atmospheres and then more and more slowly as the pressure is raised still further. At 600 pounds the voltage is less than 60 per cent of what it would be if the linear rise had continued throughout the entire range. As other workers have observed at smaller spacings, the Paschen law does not apply above about ten atmospheres.

The above results were obtained from a single sample of carefully dried air. The measurements were repeated for three other samples of air, and it was found that the results are reproducible to within a few per cent when proper care and precautions are taken to have all essential conditions the same.

However, it is possible to get breakdown voltages widely different from those that have been presented. For example, by simply sanding the flat part of the electrodes the breakdown voltage at the higher pressures can be reduced by a factor of three or four. At the lower pressures the reduction is smaller, but even at one or two atmospheres it may be as much as 25 per cent for the first few sparks.

The detrimental effect of roughening the electrodes can be overcome by prolonged sparking. At low pressures the voltage rises rapidly with the first few sparks and quickly attains a maximum value. At higher pressures the maximum voltage is not attained until several hundred, or possibly thousands of sparks have passed. The beneficial result from sparking may be termed electrical conditioning of the electrodes and the measurements so far presented apply to completely conditioned electrodes. The results for such electrodes were found to be independent of the polarity of the generator or of the sample of air; they were the same when measurements were made with ascending or descending pressures.

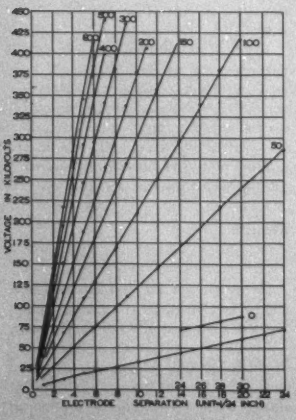

Figure 5. Breakdown voltages for plane electrodes in air at various constant gauge pressures

Figure 7 shows the effect of electrode conditioning on the breakdown voltage for a one-fourth-inch separation. The upper curve applies to well-conditioned electrodes, and the two lower curves to roughened electrodes; roughening has reduced the breakdown voltage by a factor of only two in this case. The two remaining curves apply to electrodes which have been partially conditioned. Both show the significant fact that conditioning is completed at the lower pressures before it is at the high ones. The curve which exhibits a maximum is of interest in that it shows how a carefully taken set of measurements may yield entirely misleading results. A considerable amount of conditioning was effected during the taking of these measurements because a number of spacings were studied at each pressure; only the results for the one-fourth-inch separation are given. The different points on this peaked curve therefore correspond to different amounts of electrode conditioning. This is not true for the other curves because their points were taken in quick succession using only one separation. The peak occurred because an amount of conditioning sufficient to compensate for the 100-pound reduction in pressure accrued between the time the one-fourth-inch point was taken at 600 pounds and the time the corresponding point was taken at 500 pounds. The anomalous results obtained by Ceruti,[4] where he found breakdown voltages increasing faster than either pressure or separation, may well have been caused by conditioning phenomena.

The conditioning process is evidently an electrode phenomenon. To verify this the sample of gas was changed (pressure = 500 pounds) when conditioning was partially complete and again when fully complete; in neither case was the breakdown voltage affected. Furthermore it seems that it is the irregularities on the electrodes which are responsible for the reduction in breakdown voltage; the sparking presumably burns off the irregularities. A compelling reason for believing this is that at small spacings tiny flashes can generally be seen on the surface of rough electrodes at the instant of sparking. They disappear by the time the conditioning process is completed. That the irregularities involved are extremely small is evidenced by the fact that no surface was produced which did not need some conditioning; the most satisfactory one was made by using the finest sandpaper, then crocus cloth, and finally buffing with rouge on a cloth wheel.

Other investigators have also mentioned that the breakdown voltage is augmented by operation of the apparatus; Wien[49] gives numerical values indicating a 20-per-cent improvement with use. Evidently a variety of results can be obtained for a given set of conditions with any apparatus and it is, therefore, necessary when reporting results to specify definitely the conditions under which they were taken. It is not unreasonable to suppose that part of the lack of agreement among the results of the different workers may arise from this source, since

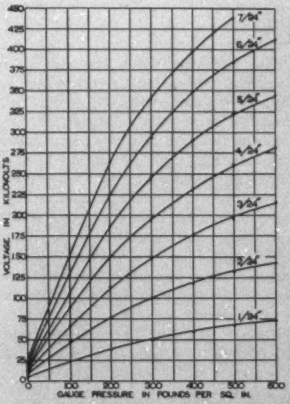

Figure 6. Breakdown voltages for plane electrodes in air at various constant spacings

the magnitude of the conditioning effect may be large.

The present procedure of quoting fully conditioned values may be misleading. It was done because these were the only values which were found to be reproducible. From an engineering standpoint it would seem that they are much too optimistic. From the standpoint of making comparisons with other results it leaves something to be desired because the amount of conditioning possible with each apparatus is presumably different.

But how can tiny irregularities on the surface of the large electrodes produce such a reduction in the breakdown voltage? In order to understand this it is

necessary to know the important physical aspects of the breakdown mechanism at higher pressures. A knowledge of these processes is also necessary to explain the results obtained with fully conditioned electrodes and the reason for the failure of Paschen's law here.

It was mentioned earlier that in the ordinary sparking phenomenon for the common gases the important mechanisms are probably the so-called α, γ, and η processes, with the additional consideration of field distortion due to space charge. Photoionization was also mentioned for long sparks in mixed gases. These processes are doubtless also at work at the higher pressures.

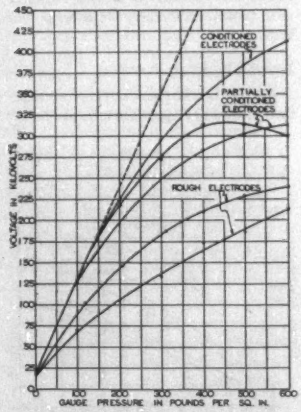

Figure 7. Effect of electrode conditioning on the breakdown voltage for plane electrodes in air at one-fourth-inch spacing

It has been suggested that the role of space charge becomes increasingly important as the pressure is raised and that the field distortion produced by it is the reason for the failure of Paschen's law at higher pressures. The assumption is that at pressures below ten atmospheres the effect of space charge is small and the field is uniform. The density of the space charge increases with the pressure and at about ten atmospheres it is sufficient to cause the gradient at the cathode to rise above the average gradient; at this time the breakdown voltage ceases to rise linearly with the pressure. Indeed, the hypothesis seems plausible, but it does not explain the detrimental effect of electrode roughening. Surely it teaches that the breakdown is initiated in the overstressed cathode region and that only the cathode irregularities are of importance. Roughening only one electrode should, therefore, introduce a polarity effect. This experiment was carried out and it was found that sanding the surface of one electrode reduced the breakdown voltage for both polarities by approximately the same amount.

The space-charge hypothesis may be modified to explain the lowering from roughnesses by assuming that self-sustaining point discharges are set up on the minute surface irregularities. Since a discharge of this type may exist on either a positive or a negative point, the detrimental effects are not restricted to roughnesses on the cathode. Lowering from points on the cathode could be caused by the space charge as explained above. Lowering from points on the anode might be due to the chaining of electron avalanches as discussed with the results for the point-to-plane configuration.

The existence of point discharges seems more reasonable when the current flow is considered. Figure 8 shows the current-voltage characteristic for plane electrodes at various stages of the conditioning process (one-fourth-inch separation, 500-pounds pressure). The actual numerical values should not be depended upon because they vary a great deal. It will be observed that this characteristic always has the shape one would expect for a point discharge. Further, it is difficult to account for current of this magnitude without assuming that a self-sustaining discharge exists; it definitely cannot be accounted for on the basis that it is the normal predischarge current which was discussed in connection with figure 2.

The point-discharge assumption is also consistent with the fact that roughnesses are less effective in producing voltage reductions at low pressure. Here the mean free path is longer than at high pressure, and only a few irregularities are of sufficient magnitude to permit the discharge to be established. The first few sparks remove these and conditioning is complete. At higher pressures, where the mean free path is reduced, point discharges can take place from smaller irregularities. Those are probably more numerous, making it necessary to pass many sparks before the conditioning is complete.

That the current-voltage characteristic retains its shape and the current its approximate magnitude throughout the conditioning process is also in harmony with the hypothesis. For very rough electrodes the discharges easily take place from the big irregularities and only a relatively low voltage is required. When the larger irregularities are removed a higher voltage is required for the discharge, and the curve for the current is shifted along the voltage scale as was shown.

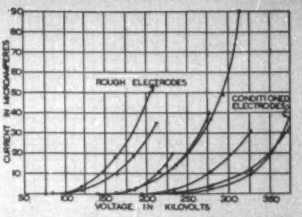

Figure 8. Effect of electrode conditioning on the current flow between plane electrodes (air at 500 pounds, one-fourth-inch spacing)

The point-discharge hypothesis is further fortified by a second method of conditioning the electrodes. It was found that conditioning could be effected by maintaining the voltage just below the breakdown value for relatively long periods of time. Conditioning amounting to perhaps 80 per cent of that realizable by sparking could be produced in 20 or 30 hours. The self-sustaining point discharge tends to remove the irregularity on which it was formed, and in these long periods this could produce a goodly amount of conditioning. It also seems probable that this method would not be capable of carrying the conditioning as far as the sparking process would carry it.

The space-charge hypothesis and the modification of it that has been suggested are not the only plausible processes which apply to breakdown at high pressures. It has also been suggested that Paschen's law fails because the gradient at the cathode becomes so high that field emission initiates breakdown. At ten atmospheres, where the law begins to fail, the average gradient is somewhat less than 0.4×10^6 volts per centimeter. The actual gradient is modified by the presence of space charge as well as by surface irregularities, and it may be possible under existing conditions that field emission becomes an important process. This hypothesis is easily able to account for the reduced breakdown voltages found with the roughened electrodes. But it certainly demands that roughnesses on the cathode are the important ones, and therefore that a polarity effect should exist. The absence of such an effect appears to be an irreconcilable contradiction of the hypothesis.

Another possibility is that the effect of the high field enters by lowering the potential barrier at the cathode, thus facilitating the escape of electrons.

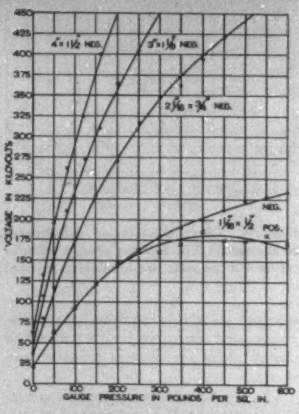

Figure 9. Breakdown voltages for cylindrical electrodes in air (inside cylinder positive and negative)

Either the γ mechanism, which assumes that positive ion bombardment of the cathode regenerates primary electrons, or the η mechanism, which assumes that photoelectric effects at the cathode regenerate the initial electrons, could be aided by such a field. Certainly this would occur at gradients lower than the values which are necessary for cold emission and the resultant lowering would set in gradually. This hypothesis, like that for field emission alone, is admirably suited to explain lowering of the breakdown voltage by irregularities on the cathode, but fails to account for the absence of a polarity effect.

Of the hypotheses which have been presented, only one seems to be consistent with the observations relating to the voltage lowering with rough electrodes and the current flowing between them. But this does not mean that the point-discharge hypothesis is to be used alone. Indeed it is able to explain only the voltage lowering due to irregularities and does not account for the failure of Paschen's law that is observed at higher pressures with fully conditioned electrodes, unless it is assumed that the electrodes can never be entirely free from irregularities which are important at the higher pressures. There is some evidence to support even this assumption in that it was found that there was always some current flow at high pressures prior to sparking.

Another phenomenon that was observed at low as well as high pressures is that after a delay of ten hours or more it was generally found that the first few sparks occurred at a somewhat reduced voltage. This is understandable if one supposes that minute irregularities are produced on the surface either by rusting action or by the settling of dust particles on the surface.

Concentric Cylinders

The results for the four sets of cylindrical electrodes are shown in figure 9. The smallest pair of cylinders showed a clear-cut polarity effect at the high pressures. The larger ones showed a decided polarity effect, and in addition the measurements for them were especially uncertain for the positive polarity (inside cylinder positive). For this case there seemed to be no definite breakdown voltage which could be reproduced. At the higher pressures the values ranged from about 50 to 80 or more per cent of the breakdown voltage for the negative polarity. In this respect the behavior of the cylinders was somewhat like that of the positive point-to-plane configuration. This might be expected since the cylinders present a less severe case of a nonuniform field. A conditioning effect was also present; however, the improvement with sparking was often suddenly terminated by a burst of sparks and a great reduction in the breakdown voltage. The voltage usually improved with further operation, but the lowering was ultimately repeated. This behavior suggests that the sparking did not always improve the electrodes, but sometimes damaged them. For the negative polarity the cylinders behaved like plane electrodes with regard to conditioning.

It is something of a surprise to find that the positive polarity supports the smaller voltage at high pressures. The field emission hypothesis, the modification of it, and the space charge assumption, all indicate that the reverse ought to be true. The point discharge proposition is again the only one of those proposed which seems to agree with the experimental results.

In the present case of a nonuniform field the self-sustaining discharge must always be formed on the inner cylinder. Then to account for the polarity effect observed, it is necessary to assume that at high pressures the positive point is somewhat more effective in producing voltage lowering than the negative point. One might also conclude that its action is somewhat more erratic since measurements for the positive case were always characterized by some uncertainty. This is in agreement with the results obtained for needle points, which will be discussed in the following section.

Throughout the experiments tiny flashes could be observed on the inner cylinder at the instant of sparking. As with the plane electrodes, currents were associated with roughened surfaces and the current was reduced by conditioning.

Table I shows that only two experimenters have previously studied breakdown as a function of pressure for concentric cylinders and that both have used alternating potentials. The polarity effect reported here is evidently new. The results of Finkelmann,[11] which show that the alternating voltage increase above ten atmospheres is small for air and N_2, agree with those reported here for direct potentials.

Needle Point to Plane

For the needle-point-to-plane arrangement only a few typical results can be included. Measurements were made on a number of gas samples for the electrode spacings, one-fourth inch, one-half inch, one inch, and two inches. Quantitative results will be given only for air and for one spacing.

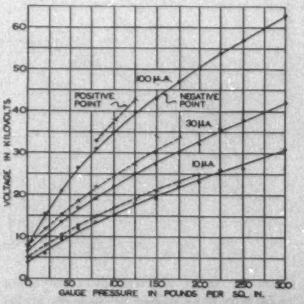

Figure 10. Voltages to produce specified currents in air with point-to-plane electrodes spaced one-fourth inch

The results for the needle-point-to-plane arrangement can best be introduced by considering figure 10. Here the voltages required to spray definite currents of 10, 30, and 100 microamperes are plotted as a function of pressure for both polarities of the point. It will be observed that the voltage does not increase as rapidly as the pressure and that it is not greatly different for the two polarities. Also, the curves for positive polarity do not extend above 200 pounds per square inch. The reason is that above this pressure a steady point discharge cannot be maintained from a positive point; a spark occurs instead. The curves for the negative point are arbitrarily stopped at 300 pounds;

they extend to 600 pounds, and no doubt beyond.

That a critical pressure exists is shown in another way in figure 11. Here the upper curves represent the sparking voltage for a positive point and the lower curves show the normal current flow just before sparking occurs. The voltage rises until a pressure of about 100 pounds is reached, then it becomes uncertain and may have any value between the two curves shown, finally at 150 pounds dropping suddenly to the initial potential curve. The initial potential is the voltage at which the point discharge and, therefore, appreciable current flow start. The current curve behaves in a somewhat similar manner. Two important exceptions are that it falls to zero above the critical pressure and that it exhibits a peak at low pressures. It will also be observed that the critical pressure is not 200 pounds as it was for the set of curves shown in figure 10. The reason is that the former results apply to a new needle point, whereas these apply to one that had been dulled by use. The dull point was employed because it does not change appreciably with a reasonable amount of sparking. It is a significant fact that the

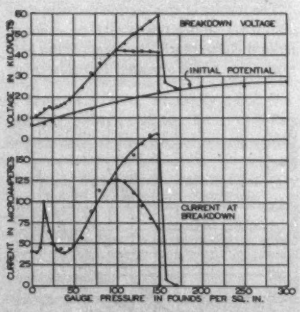

Figure 11. Voltage and current characteristics for positive-point-to-plane electrodes spaced one-fourth inch in air

critical pressure is lower for a dull point than for a new one.

The sudden rise in the current curve at very low pressures is associated with a change in the appearance of the visible discharge. At atmospheric pressure a dull point maintains a glow just at the tip of the needle, though sometimes a faint beam extends across to the cathode. When the pressure is increased a few pounds, the discharge (usually a glow but sometimes a brush) suddenly lengthens and the current rises. At first it extends across to the cathode, but it shortens and the current drops rapidly as the pressure is further raised. With still higher pressures the current again increases but the dimensions of the discharge continue to diminish. The shortened discharge takes on a variety of forms and each gives a different result; hence measurements are difficult to reproduce.

Visual observation of the sparks from a positive point revealed that they behave in a peculiar way. At low pressures they pass straight across the gap. This continues to the 100-pound point, which marks the start of the uncertain measurements. At this pressure the sparks do not always follow the shortest path but are spread out. The spreading becomes more pronounced as the pressure rises until the critical pressure is reached, then it becomes very slight again. Thus, spreading of the sparks seems always to be associated with uncertain measurements.

The photographs in figure 12 illustrate the type of results that can be obtained; the spreading was observed for all spacings. Each exposure shows a number of single sparks spaced about one-fourth or one-half minute. It will be observed that the sparks leave the point at many different angles and some travel a short distance in the direction away from the plane electrode. Some of the photographs suggest that the sparks never follow the shortest path when the spreading is manifest. The possibility could be investigated by making simultaneous observations from different angles, but this was impossible with the apparatus used.

The results for a dull negative point are shown in figure 13. The voltage curves are typical of all that were obtained for negative points. The current curves for other conditions, however, sometimes exhibited a minimum value. Sparks from a negative point always followed the shortest path and the steady discharge always existed as a glow of approximately constant size.

The current-voltage characteristic for both positive and negative points was studied as a function of pressure. It was found that for either polarity the shape was substantially independent of pressure. Figure 14 shows the results for a one-half-inch separation; six sets of data are plotted for the positive point (0, 15, 30, 50, 100, and 150 pounds pressure), and five sets of data are given for the negative point (0, 100, 200, 300, and 400 pounds). When reduced to a percentage basis the curves for different pressures are in surprising agreement. In making the computations the breakdown voltage was taken to be the 100 per cent voltage and the normal current flow corresponding to a voltage just below the breakdown value was taken to be the 100 per cent current.

The results that have been given for the positive point can be understood by considering the space charge left by the electron avalanche as it moves toward the point. At low pressures the density of the space charge in the avalanche path is too low to cause significant field distortion. Furthermore the ions are quickly moved out of the avalanche path by diffusion. As the pressure increases, the density of space charge in the avalanche path rises and diffusion decreases with the result that at higher pressures the field does become distorted by space charge and the ions remain in the path of the avalanche for relatively long periods of time. Under these conditions the space charge filaments constitute new points toward which other electron avalanches may be directed. The pressure at which the spark spreading starts is that for which the space-charge filament is dense enough to direct electron avalanches to itself. The fact that the space charge concentration remains for a relatively long time permits the effective electrode configuration to be built up in peculiar forms through a series of successive avalanches, and thus when the spark occurs it is led to the point over long and irregular paths. The measurements are uncertain because the electrode configura-

Figure 12. Spark spreading for positive-point-to-plane electrodes spaced one inch in air

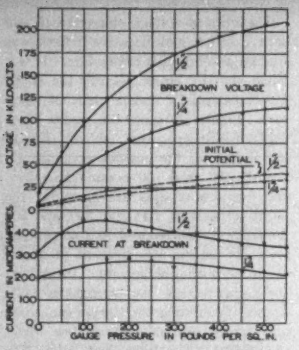

Figure 13. Voltage and current characteristics for negative-point-to-plane electrodes spaced one-fourth inch and one-half inch in air

tion is uncertain. That the pressure at which the uncertain phenomenon begins is lower for the larger electrode separation is understandable. The large number of ions in the interspace reduces the actual field in the vicinity of the point with the result that ion filaments of reduced density are able to direct electron avalanches toward themselves.

The above hypothesis readily accounts for the observed behavior of the sparks in the unstable region, but it does not explain how the chance mechanism is suddenly terminated by the appearance of a stable behavior. A possible explanation of this critical pressure is the occurrence of thermal ionization of the gas. At high pressures the large amount of heat energy developed by the avalanche is not effectively removed through diffusion and thermal conductivity. The temperature in the avalanche path rises with pressure until it becomes sufficient to dissociate and ionize the gas molecules and when this happens a new type of sparking mechanism presumably sets in. The point discharge causes, through progressive thermal ionization, the effective point to be projected toward the cathode until breakdown results. On this sort of basis it is reasonable that the sparking potential should coincide with the initial potential, and that scattering of the measurements and uncertainty of the spark path should cease.

Another possible interpretation of the positive point behavior is that the space charge near the point reduces the gradient at the apex, as previously suggested, until the actual gradient there is less than the gradient in the radial direction from the side of the needle. When this happens the sparks leave the needle radially in order to follow the strongest field. Since they would all tend to avoid taking the shortest path, this would explain the photographs that show no short paths. In this connection it would be helpful to establish whether or not any of the sparks follow the shortest path.

The existence of a critical pressure may also be explained on a space charge basis. Normally the geometric field of a point-to-plane arrangement is such that the point discharge is stable. But as the pressure is raised the amount of space charge in the interspace is increased and this makes the actual field more nearly uniform. Finally the tendency of the space charge to make the field uniform overcomes the stabilizing nature of the geometrical arrangement to such a degree that a stable discharge cannot be maintained.

It has been mentioned that a negative point does not exhibit the uncertain region or the critical pressure which has been discussed. This can be understood since the electron avalanche inherently spreads as it moves away from a negative point and therefore does not permit filaments with a high space-charge density to be realized. Also the field at the apex of the needle is increased by the space charge and not diminished.

In order to test the thermal ionization hypothesis the studies so far described for air were repeated for nitrogen, again for helium with three per cent nitrogen, and finally for a mixture containing equal partial pressures of the two gases. The ions involved in the breakdown are nitrogen ions in all these cases. Since the helium has more than six times the thermal conductivity of nitrogen, the helium-nitrogen mixtures carry the heat energy out of the avalanche paths more rapidly than nitrogen. The nitrogen ions also diffuse more readily through helium than through nitrogen. Because of these two effects, thermal ionization in helium-nitrogen mixtures should not begin at as low a pressure as in nitrogen alone.

The experiments showed definitely that the critical pressure is much higher for the helium mixtures than for nitrogen. The results for a one-fourth-inch spacing showed that the critical pressure was 190 pounds for pure nitrogen, approximately 500 pounds for helium mixed with three per cent nitrogen, and 350 pounds when equal partial pressures of the two gases were used. Similar results were obtained for other spacings. Either thermal conductivity or diffusion or both would cause the results for equal partial pressures of the two gases to fall midway between the others as they do.

The spreading of the sparks was smaller for nitrogen and for helium mixed with three per cent nitrogen than it was for air. But for equal partial pressures of the two gases the sparks spread as much or more than they did for air.

An experiment by Goldman and Wul[13] for pure nitrogen at 100 degrees centigrade showed that the critical pressure at this temperature was greater than it was at 13 degrees centigrade. About half of the rise they observed was due to the change in the density of the nitrogen with temperature. An increase was still manifest and this was probably largely caused by the increased diffusion at the higher temperatures. Their results were also in harmony with the thermal-ionization hypothesis.

One bit of interesting information that came out of this study of points is that the dissociated oxygen which resulted from the discharge caused a very rapid rusting of the electrodes and the tank walls. A brown dusty appearance could be detected after very few hours' operation. The deposit was collected for some time and analyzed spectrographically. It was found to be principally iron, nickel, and chromium, with traces of impurities likely to be found in the metal.

The results of this section indicate that additional difficulties would be encountered if electrostatic generators of the belt type were to be operated in compressed

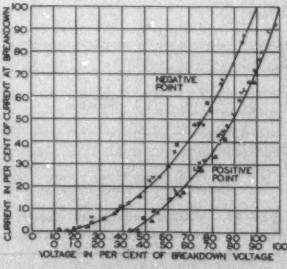

Figure 14. Current-voltage characteristics for point-to-plane electrodes in air at various pressures

gases at pressures above the critical pressure. It appears that the operating requirement which specifies that the two parts of the belt be equally and oppositely charged cannot be met when positive charge cannot be sprayed on the belt. The results also reveal theoretical information which is of interest in the study of breakdown at high pressures. This is of importance since evidence is at hand

to indicate that the point discharge is of particular significance in all high-pressure breakdown, especially when rough electrodes are employed.

Conclusions

Breakdown measurements made with plane electrodes were found to be greatly reduced by surface roughnesses, the percentage of reduction increasing with pressure. Both visual observations and current measurements lend strong support to the belief that the lowering is brought about by point discharges proceeding from the irregularities. Prolonged sparking was found to reduce the detrimental effect of roughening. Experiments demonstrated that this beneficial effect is definitely not brought about by changes produced in the air sample. Both the effect of electrode roughnesses and the conditioning phenomenon are of real practical importance. The significance of electrode roughnesses at high pressures may make measurements under laboratory conditions appear too promising.

The cylindrical electrode arrangement showed a definite and surprising polarity effect; the measurements were lower and more uncertain when the inside cylinder was positive. Further, it was not possible to realize complete conditioning for the larger cylinders. Applications of compressed gas using a cylindrical arrangement should naturally employ a negative polarity on the inner cylinder when possible. This may be accomplished in the case of a d-c cable, but not of course in the common condenser application where alternating potentials are used.

With the needle-point-to-plane electrode configuration the two polarities yielded entirely different results. The voltage and current for a positive point increased with pressure for the first few atmospheres, then became indeterminate, and ultimately a critical pressure was reached at which the voltage fell to the initial potential value and the current to zero. In the pressure region where the measurements were indefinite the path that the spark followed was uncertain. Above the critical pressure the spark path again became regular and the voltage was definite. The results for a negative point showed no irregularity.

The critical pressure for nitrogen and for air was substantially the same, approximately 200 pounds; for helium mixed with three per cent nitrogen it increased to about 500 pounds; for equal partial pressures of the two gases it amounted to 350 pounds.

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50. Über den Widerstand von Gasen gegen disruptive Entladung bei höherem Druck, Max Wolf. *Wiedemann-Annalen der Physik*, volume 37, 1889, pages 306–15.

51. Durchschlaguntersuchungen in komprimierten Gasen und in flüssiger Kohlensäure, O. Zeier. *Annalen der Physik*, series 5, volume 14, 1932, pages 415–47.

Discussion

G. C. Nonken (General Electric Company, Pittsfield, Mass.): Alvin H. Howell is to be commended on his review of the past work done on the dielectrics of high-pressure gases. Likewise, on his own work which has extended the combined voltage-pressure range to a considerably higher value than has previously been recorded.

It is of practical importance to compare the breakdown strength of air at high pressures with the breakdown strength of other typical high-voltage insulation. The important thing that shows up in such a comparison is that whereas the d-c breakdown of compressed air expressed in volts per mil is constant for different spacings as shown by Mr. Howell's figure 5, the dielectric strength in volts per mil of solid and liquid dielectrics drops off very rapidly with increased spacing. (The breakdown strength of solid insulation varies about as the two-thirds power of the spacing.) In making three typical comparisons we find that the d-c breakdown strength of five-mil thickness of good solid insulation is over three times higher than the same thickness of compressed air at 500 pounds pressure; the d-c breakdown strength of one-half-inch good solid insulation is slightly stronger than a half-inch of air at 500 pounds pressure; while 0.1 inch of transil oil is only about one-third the strength of air at 500 pounds pressure with d-c applied voltage. These comparisons would undoubtedly be much different on the basis of alternating or impulse voltages instead of direct voltage, or if the comparisons were made with other than parallel plate electrodes. It appears that if high-pressure gas is to be used as a dielectric, it will be in the ultrahigh-voltage field, where the insulation spacing is an inch or more.

In 1935, I made some tests on the corona current on a point-to-plane gap in air. I observed that the corona current, when the point was negative, was composed of a series of high-frequency current pulses which involved frequencies higher than 1,000 kilocycles. These current pulses built up very rapidly and then fell off exponentially to zero. The frequency of occurrence of these pulses was quite regular and increased with the applied voltage. With a positive point, a pulsating corona current occurred at the first initiation of corona, but at slightly higher voltage, the corona current changed to a steady state. These pulsating corona currents point to the important part which space charge has on the mechanism of breakdown. I would like to ask Mr. Howell if he observed this pulsating-corona-current phenomena in his tests, and if so, would the microammeter which he used record correctly the average value of these high-frequency currents.

I have observed the critical pressure in the breakdown versus pressure curve of sharp-edged gaps; similar to that shown in Mr. Howell's figure 11.

One test setup consisted of rod gaps tested with 60-cycle voltage in nitrogen. The critical pressure for that arrangement was 140 pounds per square inch gauge, and was not typified by such an abrupt discontinuity in the voltage breakdown curve as is shown in figure 11.

G. W. Dunlap (General Electric Company, Schenectady, N. Y.): Mr. Howell has done a very creditable piece of work and his paper presents valuable additions to the growing fund of information about the dielectric strength of gases at pressures above atmospheric.

Several questions arise and perhaps some related findings from the experience of the writer in a similar investigation may be pertinent.

The comments about the mechanism of breakdown are quite interesting and throw a new light on this phase of the subject. A better understanding of this mechanism is, of course, vital to the application of gases under pressure to the insulation problem. Regarding this point, the following questions might be answered.

Does not the same mechanism account for the departure from the Paschen relation with "uniform fields" as well as the critical pressure effect found with the point plane? It would seem to be a matter of degree.

Inasmuch as all the tests reported were made with direct current, it is possible that the full importance of space charge is not appreciated. This effect is more apparent when voltages with different time-amplitude characteristics are applied. For example, a six-centimeter rod gap in nitrogen at four atmospheres absolute was found to have a breakdown value of about 150 kv with 60-cycle voltage and a value of only 120 kv for a $1^1/_2 \times 40$ positive impulse. This is, of course, directly opposite to the usual relation between impulse and 60-cycle breakdown.

In the study of dielectric breakdown it is well to be careful in drawing conclusions about the mechanism of breakdown on the basis of currents flowing before breakdown. Insulation studies in general have shown a decided lack of correlation between such current conditions and the actual breakdown.

Also can atoms remain in a metastable or excited state long enough to effect the strength of a given volume of gas for a time in the order of tens of seconds? In tests where positive impulse voltages were applied to sphere and rod gaps in gases under pressure it was found that the strength of a given gap depended to some extent on the preceding voltage application. Almost invariably the application of an impulse at some level within the range of voltages that could produce breakdown would cause a flashover if there had been a flashover on the previous application. Conversely, if there had been no flashover on the preceding application, the same voltage would be withstood and the voltage could be raised to the upper limit before a breakdown would occur. Impulses were applied at intervals of approximately one-half minute so this phenomenon is not satisfactorily explained by the usual conceptions of ionization by impact or electric or thermal stress.

Concerning the effect of roughening the electrodes, was any relation noted between the amount of effect and the spacing of the electrodes? It seems reasonable that the presence of small points could produce changes of the magnitude reported. Experience of the writer in corona studies seemed to indicate a measurable effect from irregularities of microscopic size on bare copper cables for high-voltage transmission lines.

Figure 11 of the paper shows a maximum breakdown voltage at 150 pounds though the conclusions give a value of 200 pounds. Was any relation noted between the critical pressure and electrode spacing? For standard one-half-inch square rod gaps in nitrogen the writer found breakdown voltage maxima at four atmospheres absolute for both positive impulse and 60-cycle voltages. There was some indication that this critical pressure decreased with increasing gap lengths.

The attack on metal parts mentioned as due to dissociated oxygen should be remembered if application is to be made where frequent breakdowns could occur. Similar trouble has been experienced where gases of complex molecular structure have been used. The use of an inert gas such as nitrogen obviates this difficulty.

In the engineering application of gases under pressure it is important to remember the wide range of dielectric strengths obtained by varying such factors as the field configuration and the polarity of applied voltage. This is emphasized by the results given by Mr. Howell. It is impossible to design gas-insulated apparatus on the basis of a pressure-breakdown curve for one gap.

Victor Siegfried (Worcester Polytechnic Institute, Worcester, Mass.): Mr. Howell has presented a fine piece of work on a very important line of research, and is to be commended on the thoroughness with which the investigation was made. Many of the features of high-pressure gaseous insulation have been determined and the limits within which developments may be expected for an application of gas under pressure for insulation are shown to be elastic but high as compared with practice up to the present. Mr. Howell's discussion of the effects noted with regard to conditioning of electrodes is particularly appropriate. It is obvious that for any commercial development of long lengths of cable, little or no condition-

ing effect will be realized and that the real practical limit is established by results for rough electrodes, as shown in figure 7 of his paper.

An investigation of pressure relations with gas for a dielectric at Worcester Polytechnic Institute has shown similar results to Mr. Howell's, in that for unconditioned electrodes, there is a distinct disagreement between points on the breakdown curve taken with increasing pressure and those taken with pressure decreasing. The trends are quite definite, and it seems to make little difference as to the order in which the tests are made. The specimen used is a concentric cylinder with a ratio of outer to inner diameter of about four, flashed over with alternating potentials, and of a length so that previous sparking of the gap produces little conditioning, since as soon as one spot becomes conditioned, another point takes the arc under approximately the same conditions as the first. This gives rise to the belief that the effect is more than an electrode effect entirely, yet it is difficult to understand how the gas can be affected directly by the direction of pressure change. The factor of time seems to play no part, as the gas can be left at any pressure for a length of time on either curve and still show a wide separation between rising and falling pressure values. The investigation of this phenomenon would help in arriving at the practical limits for gas-pressure insulation.

I would like to suggest another point of significance from the practical side of the discussion. The ratio of cylinder diameters at very near to ϵ, as used by Mr. Howell, gives results which will seldom be achieved except under laboratory conditions. The interesting values of this ratio are those slightly above ϵ, since the corona-free breakdown given by the curves in this paper is a very special type of spark-over. Further work of the same caliber as Mr. Howell's should be undertaken with a wide range of cylinder diameter ratios. Results from such a set of tests may help to clear up some of the baffling phenomena observed and possibly improve the test procedure to a point where observations will not be affected by sudden bursts of violent sparking, since some corona will be present to initiate slow discharge before complete breakdown ensues.

Mr. Howell has attempted to explain many of his results from fundamental concepts, but has had to throw out many possible explanations because they do not fit one observation, namely, the lack of difference in breakdown voltage for a reversal of polarity. I do not see how the polarity can be definitely biased for plane electrodes, and for cylinders the results are already counter to polarity theory; so that my own feeling is that there may be more to Mr. Howell's explanations than he has allowed on the basis of the one key observation. I hesitate to suggest that his work is in error, for I can certainly do no better than he has done, but it may be that the sensitivity of the measurements does not permit easy detection of a polarity effect which may be present.

R. C. Buehl (Massachusetts Institute of Technology, Cambridge): The excellent paper of Mr. Howell naturally raises the question of the extension of the results to higher pressures and alternating voltages. In this connection, two questions are of importance, namely:

1. Does the breakdown approach a definite maximum with increase of pressure, or continue to rise at a slower rate than at low pressures?

2. Will electrodes condition themselves or deteriorate when breakdown measurements are made with alternating voltages from a transformer so that each breakdown is followed by a short-time arc?

The answer to these questions for plane electrodes is contained in measurements on nitrogen with 60-cycle alternating current made by the author in 1935 with the apparatus sketched in figure 1 of this discussion but not previously published. The nitrogen was partly purified by passing over magnesium heated to 400 degrees centigrade and through a trap cooled by solid CO_2. Errors due to time lag were eliminated by irradiating the gaps with ultraviolet radiation from an iron arc but this had no appreciable effect on the breakdown voltages except to make them more consistent. A resistance of 1.8 megohms was used as a series resistance to protect the electrodes from excessive pitting. After a breakdown, the voltage was removed in a fraction of a second by a relay.

The breakdown voltages are plotted against pressure in figure 2. Below 15 atmospheres there was little spread in the breakdown measurements, all the values falling within two per cent of the average, so that the electrodes seem to have been satisfactorily conditioned. This conditioning required about 50 breakdowns. Above this pressure, the spread on the breakdown voltages became much greater, becoming as great as 15 per cent in some cases, the spread being shown by the shaded areas in figure 2. In general, each successive breakdown voltage would tend to be higher than the previous one until a maximum was reached but occasionally an arc would appear to damage the surface so that the following breakdown measurements would

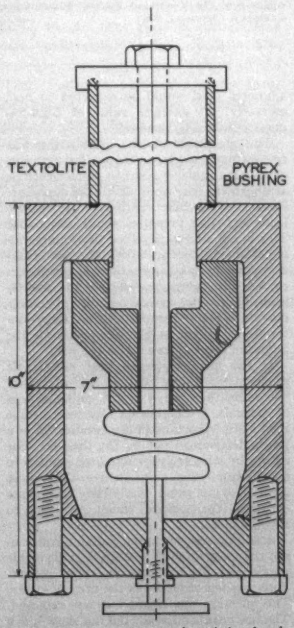

Figure 1. Apparatus employed for breakdown measurements on gas at high pressures

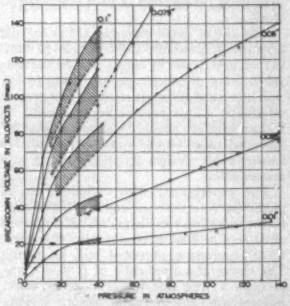

Figure 2. Breakdown voltages for nitrogen with plane electrodes at various constant separations

be at the bottom of the spread. Consequently, with the apparatus employed, the condition of the electrodes appeared to be continually changing in the range from 15 to 45 atmospheres. An interesting phenomenon was observed, namely, that sparks which lasted only a fraction of a half cycle often occurred at the lower breakdown voltages. These conditioned the electrodes so that the following breakdown voltage was always considerably higher.

Above 45 atmospheres the spread in the breakdown voltages again became small except that the sparks of short duration mentioned above occurred occasionally at voltages below those necessary to cause a repeated breakdown during each half cycle. These low breakdown voltages are not shown in figure 2. Since the extrapolations of the curves from high pressures coincide with the minimum breakdown values observed between 15 and 45 atmospheres, it appears that the irregularities on the electrodes—either points or active regions of low work function—become more important at high pressures, and their effects cannot be removed as readily by breakdown above 45 atmospheres as below. Above 45 atmospheres the breakdown voltage increases about linearly with the pressure but the rate of increase of breakdown voltage with pressure is only about one-fifth that at atmospheric pressure. This corresponds roughly to the ratio of the slope of the curves for rough electrodes at high pressures to the slope for conditioned electrodes at atmospheric pressure given by Mr. Howell in his figure 7. From this it would seem that surface irregularities, which act as points of local discharge or sources of electrons, play an important role in determining the breakdown voltages at high pressures. Although the mechanism of breakdown at high pressures is probably different from that at

atmospheric pressure, the surface irregularities probably control the breakdown voltage and largely mask the effect on the breakdown voltage of a change in the mechanism of breakdown.

E. W. Davis (Simplex Wire and Cable Company, Cambridge, Mass.): The author has carried out a most careful investigation of this subject and has gathered together a very good background of past experimental work.

The art of cable manufacture is moving forward quite rapidly and a very large number of new types of cables use or contemplate using pressure-type insulation to obtain increased dielectric strength and greater reliability. This present paper dealing as it does with gas should be of some value for gas-filled cable and of considerable use for future cable design for high-voltage d-c transmission.

The experiments with cylinders are of particular interest to us and it is hoped that future work with cylinders of varying ratio of D to d will be tried and also that tests with alternating potential will be made. The choice of a fixed ratio of $D/d = e$ was perhaps a wise one for this initial work. Breakdown tests of cables having varying ratios of D/d do not follow the theoretical formula for large ratios of D/d (over value of e) and as yet no good explanation has been offered.

Minimum stress, maximum stress, current density (pyroelectric effects), and corona-type formula have been offered without much success. In connection with this problem we are interested in the erratic behavior of concentric cylinders having the inside one positive and also with the pronounced polarity effect found which is apparently new. If this polarity effect is pronounced it is conceived that for alternating voltage there may be some rectifying action taking place which would allow the building up of space charges and explain the reason why corona-type formula apply fairly well to cables insulated with solid-type dielectrics.

The author is to be congratulated on avoiding many of the pitfalls in dielectric strength tests which sometimes lead to erroneous conclusions.

A. H. Howell: The gentlemen who have offered discussions have presented valuable material and the writer wishes to express appreciation for these contributions.

Mr. Buehl's results with alternating voltages appear to be in agreement with those for direct potentials reported in the present paper. It is especially helpful to have available these quantitative results from his work.

The comments of Mr. Davis are especially significant because of his close association with the commercial aspects of insulation problems.

Mr. Nonken has made interesting comparisons of the dielectric strengths of typical solids and liquids with those presented for compressed gases. Regarding the question he raises concerning the possible pulsating nature of the currents that were observed, this was not checked and there were no observations indicating that the current possessed this pulsating quality. The microammeter used would be expected to read correctly the average value of high-frequency pulsating currents.

The suggestion of Mr. Dunlap that the mechanism underlying the critical pressure effect for a positive point-to-plane electrode arrangement may account for the departure from the Paschen relation with uniform fields at higher pressures seems reasonable. This is not necessarily true since numerous physical processes are at work in the breakdown of a gas, and as yet there is insufficient evidence to determine whether the one responsible for the critical pressure phenomenon is wholly responsible, partially responsible, or not at all responsible for the failure of the Paschen relationship.

It has been suggested that metastable atoms may not play a part in the breakdown when the time lag is of the order of tens of seconds. Whether or not metastable atoms are important in the breakdown of a gas is determined not by the time lag, but rather by whether they live long enough to travel from the point where they were created to the point where they regenerate electrons (the cathode) which contribute to the discharge.

A definite answer to the question concerning the magnitude of the effect of electrode roughening for different electrode separations was not obtained in the present study. The question was raised but not explored. The few results obtained did not show much of an effect with separation.

The effect of electrode spacing on the critical pressure has been raised. The critical pressure for a given positive point was practically independent of spacing for the spacings used (up to two inches). It was observed that the particular point used affected the critical pressure, the pressure being lower for a dull point than for a sharp one. However, the pressure at which spark spreading and uncertain measurements began was lower for the larger spacings.

The remarks of Mr. Dunlap concerning the effect of the gaseous products of breakdown on the apparatus and of the importance of such factors as field configuration and polarity in design are most significant.

Mr. Siegfried raises the question of a polarity effect with plane electrodes. The polarity effect was expected only for the arrangement of one conditioned electrode and one rough electrode. On the assumption that breakdown is initiated at the cathode (and is not influenced by the condition of the anode) as it is with some of the suggested mechanisms, such a gap ought to exhibit breakdown voltages corresponding to rough electrodes when the rough electrode is the cathode and breakdown voltages corresponding to conditioned electrodes when the conditioned electrode is the cathode. This difference in voltage would easily be detected and was the effect expected.

The results of Mr. Siegfried's own work are very interesting and it is helpful to have the comments from his practical point of view.

Bus Protection

AIEE-EEI COMMITTEE REPORT*

THE RECENT occurrence of several serious switch-house fires has occasioned an unusual interest in the matter of bus protection. Acting upon the belief that a comprehensive survey of modern practices in such protection would be of some benefit to those interested, the relay subcommittee of the AIEE protective devices committee and the relay subject committee of the Edison Electric Institute electrical equipment committee jointly prepared and circulated a rather extensive questionnaire on the subject.

It is the purpose of this report to present factual data on the principal types of bus protective schemes as reported by the 34 companies replying to the questionnaire, and also to present a discussion of the design features involved as indicated by the replies to specific questions asked and collateral data supplied.

Paper number 39-19, recommended by the AIEE committee on protective devices, and presented at the AIEE winter convention, New York, N. Y., January 23-27, 1939. Manuscript submitted November 3, 1938; made available for preprinting December 10, 1938.

* A report prepared under the auspices of the relay subcommittee of the AIEE protective devices committee and the relay subject committee of the Edison Electric Institute electrical equipment committee by J. H. Neher, chairman of the AIEE relay subcommittee and engineer in charge of relay design for the Philadelphia Electric Company, Philadelphia, Pa., and H. L. Wallau, chairman of the EEI electrical equipment committee and electrical engineer of the Cleveland Electric Illuminating Company, Cleveland, Ohio.

Classification of Bus Protective Schemes

In order to obtain as much uniformity as possible in the scope of the replies solicited, the three principal types of bus protection were defined as follows in the questionnaire:

A. Differential Protection. The bus protective relay is operated from a differential connection of current transformers located in all sources to and feeds from the bus and therefore distinguishes between bus and external faults by virtue of its connection.

This system offers protection against phase faults, ground faults, or both, dependent upon the use of phase relays, the use of a neutral relay only, or of the latter in combination with phase relays.

B. Fault Bus Protection. The normally grounded parts in the station are interconnected through a "fault bus" which is connected to the station ground through one or more current transformers in such a manner that currents due to ground faults occurring on the bus or associated equipment must pass through this fault bus and operate a bus protective relay connected to the above mentioned current transformers. As indicated, this system offers protection only against faults involving ground.

C. Partial Differential Protection. The bus protective relay is connected to current transformers located in one or more of the sources to the bus. Operation on external faults is prevented by:

1. Utilizing an overcurrent relay with a time setting selective with the rest of the system protection under the prevailing conditions.

2. Utilizing a distance relay with a definite ohmic pickup set above the value of reactors located in the sources to or feeds from the bus; or a distance relay with a time-distance characteristic set selectively with the rest of the system protection.

This system offers protection against phase faults, ground faults, or both, according to type, and connections of the relays employed.

Numerical Data

The numerical data obtained from two general questions covering the main constructural and operational features of the installations are given in table I. Because of wide variations in the number of installations reported by individual companies, there have been incorporated both the number of reporting companies and of installations of each class reported. In general, no effort has been made to minimize the discrepancies appearing in the tabulation because of incomplete detail in the replies.

Of the total installations, three companies reported 61 per cent and six companies reported 81 per cent of the type *A* installations; three companies reported 62 per cent of the type *B* installations, while the type *C* installations were much more uniformly distributed among the reporting companies.

On the basis that all similar applications were installed at the earliest date listed by the reporting company and applied to the total bus sections so reported, it appears that type *A* installations have been in use for 11 years, type *B* for 10 years, and type *C* for 7 years to the beginning of 1938. It will be noted that this has a tendency to exaggerate their actual age.

Group phase bus construction is used in 93 per cent of the sections equipped with type *A* and in 87 per cent of those equipped with type *C* protection. The type *B* fault bus systems are primarily favored for use with indoor installations, some 82 per cent being so reported. The margin of the isolated phase installations over the group phase for type *B* is not as great as might be expected.

The voltage ranges were selected to emphasize the grouping points of the numbers of reported installations.

In respect to the type of faults protected against, the answers were tabulated as specified on the individual returns, except that type *B* installations were listed under "ground faults" only. In some cases they were specified in the "both" category and undoubtedly these installations will function properly for phase-to-phase faults involving ground. This is probably true of all the installations listed under "ground faults." Both *A* and *C* types of protection may have installations listed in the "both" category with the same thought in mind.

As regards the matter of system grounding, practically all cases involving an isolated neutral apply to distribution substations. The majority of the fault bus installations are used in connection with limited ground currents since most are installed in generating stations where this is a standard practice.

The balance current relays employed are principally of the percentage-differential type. Distance relays are of the impedance type.

One company lists 172 type *A* installations with instantaneous overcurrent relays. Sixty-six percentage-differential relays listed under "balance current" in type *A* installations are in use by another company.

It is apparent that the type of current transformer used depends primarily on the type of bus construction. The bushing type is heavily favored with the differential class of protection since most of the protected buses are of the outdoor type. In the case of the fault bus type of protection, most installations are indoors, which makes the wound type of transformer convenient.

The "combination" group contains examples of all possible groupings of the three principal classifications.

Four companies reporting about 300 installations practically all of the differential type, use the term "excellent" to indicate performance in lieu of numerical data.

Causes of Incorrect Operations

This information is sufficiently important to justify the inclusion of more

Table I. Summary of the Constructional and Operational Features of the Bus Protective Installations Reported

Classification	Total Installations		Type of Station			Type of Bus Construction				Voltage of Protected Bus (Range in Kilovolts)			Protection Against		
						Group Phase		Isolated Phase							
	Existing	Proposed	Generating	Transmission	Distribution	Indoor	Outdoor	Indoor	Outdoor	2–9	11–22	33–88	110–220	Phase Faults	Ground Faults	Both
A. Differential	26/ 803	9/38	20/172	21/379	14/288	16/245	24/533	5/ 49	1/10	6/100	22/338	14/252	14/153	9/266	8/ 47	22/484
B. Fault bus	11/ 197	2/ 5	9/132	7/ 42	4/ 28	5/ 75	5/ 15	7/ 90	1/22	1/ 6	9/165	4/ 24	2/ 5	12/198		
C. Partial differential	9/ 132	4/37	7/ 62	6/ 53	3/ 54	7/ 77	8/ 70	3/ 21	1/ 1	2/ 32	8/104	1/ 4	4/ 29	4/ 53	2/ 24	8/ 90
Totals	32/1132	15/80	28/366	27/474	15/370	22/397	27/618	14/160	2/33	7/138	28/607	16/280	17/187	10/319	18/269	25/574

Classification	Type of Grounding System				Type of Relay Protection				Type of Current Transformer				Number of Operations	
					Overcurrent									
	Solid	Resistor	Reactor	Isolated Neutral	Induction	Instantaneous	Both	Balanced Current	Distance	Bushing	Through	Wound	Combination	Total	Incorrect
A. Differential	20/415	15/333		5/87	11/258	8/386	3/ 41	16/150	1/ 4	21/613	10/121	10/ 52	6/30	13/155	10/32
B. Fault bus	6/ 62	5/121	1/ 8		4/ 14	7/ 91	3/ 94			2/ 39	2/ 51	7/ 97	1/ 3	10/ 55	5/15
C. Partial differential	7/ 92	6/ 39	2/ 4	2/10	4/ 53	2/ 25	1/ 4	3/ 47	2/19	5/ 69	4/ 37	4/ 37		3/ 4	1/ 1
Totals	22/569	16/493	3/12	6/97	16/325	14/502	7/139	16/197	3/23	21/721	13/209	19/186	7/33	22/214	16/48

NOTE: The figures to the left of the oblique bars designate the number of reporting companies while those to the right of the oblique bars designate the number of bus sections reported.

detail from the individual returns.

Number of Incorrect Operations	Causes
8	Incorrect wiring.
4	Errors in routine testing, such as applying potential to the ground bus.
1	Differential relay failure.
5	Improper application, principally failure to consider current transformer ratio changes under high fault currents.
3	Construction errors. In one case this was a matter of poor contact and in another construction men inadvertently cut into an operating bus protective setup and the third was caused by vibration from construction on an adjacent panel.
2	Failure of bushing current transformers.
2	Balance circuit grounded.
1	Auxiliary relay failure.
8	Faulty insulation of fault busses. Other cases of this are mentioned.
8	Minor miscellaneous causes.
"Several"	Unbalance created by d-c transients at the time of a fault.

Maintenance

Maintenance of bus protective systems is quite evenly divided between the "negligible" and "reasonable" categories. No reporting companies consider the maintenance of their present bus protective systems as "heavy."

The usual maintenance periods reported by the various companies are as follows:

3 months—reported by 3 companies with 71 installations

6 months—reported by 11 companies with 480 installations

12 months—reported by 15 companies with 434 installations

24 months—reported by 2 companies with 157 installations

Included in the above tabulations are some companies with a relatively large number of installations which divide them into two categories in order of importance and provide maintenance accordingly.

A 6- and 12-month interval is so used by three companies with 227 installations. Two companies with 277 installations use 12- and 24-month maintenance periods.

Four companies reporting 287 installations provide some or all of these installations with instruments on which the condition of the balance is read three times daily.

Several companies provide tripping tests and/or inspections at intervals between the normal maintenance periods given above.

Design Features

A number of specific questions were asked in reference to the three main protective systems, intended to promote a discussion of certain features fundamental in their designs, and the following discussion has been prepared from the replies. Outlines are also included of special bus protective schemes which are believed to be of general interest.

Differential Bus Protection

(*a*) *Current Transformer Considerations.* The highest ratio of fault current to current-transformer rating varies considerably and attains the remarkably high value of 126 to 1. The conservative limit of 10 to 1 or less is used by five companies reporting 316 installations. The most commonly used limits are within the range of 11 to 20 to 1. Twelve companies report 300 installations in this group. The 21 to 30 to 1 class has a substantial representation consisting of 138 installations reported by seven companies.

Higher limits are used by three companies reporting 66 installations which are probably permissible because of special conditions. A conservative trend is clearly indicated by a consideration of proposed installations. These show that the limiting ratios will be lowered by five companies and raised by one and will exceed 20 to 1 in one case only.

Eight companies reporting 264 installations include an accuracy limitation in current-transformer specifications. Classification of these is difficult since most of the specifications are not complete and lack agreement. The limits range from 0.5 per cent to ten per cent at ten times rating.

Nineteen companies reporting 546 installations use standard transformers with commercial accuracies. However, a growing consciousness of the accuracy factor is apparent as three of the latter companies now include some specification of accuracy in proposed installations.

Opinion favors the independent grounding of current transformers. Eighteen companies reporting 307 installations follow this practice. Seven companies reporting 394 installations use a common ground, generally located at the relay panel and providing a convenient point to megger the relaying circuits.

One company reporting 179 installations uses a single ground for all installations except those on 4.8-kv busses which use independently grounded current transformers. Of particular interest is the fact that these ground connections, in recent practice, are made up of a 300-ohm resistor with a parallel gap. This reduces the hazard of a false operation if the circuit is accidentally grounded and at the same time is believed to afford adequate safety to personnel and equipment.

With a single exception no inclination to change existing practice is indicated in the proposed installations.

A relatively even division of opinion exists on the permissibility of utilizing current transformers of different ratios equated by autotransformers with 14 companies reporting 288 installations subscribing to this practice and 12 companies reporting 523 installations avoiding it. Of the latter, two companies use balancing transformers if a transformer bank is included in the protection. Balancing transformers are all of the autotransformer type with the exception of those used by three companies who prefer the tapped two-winding type.

It is evident that balancing transformers should preferably be avoided whenever possible, but sufficient evidence exists to indicate that it is perfectly feasible to use them if the situation requires.

If protection against ground faults only is provided existing current transformers are generally used according to reports from nine companies with 175 installations. Separate current transformers are used by three companies reporting 11 installations. Both types are used by one company reporting 9 installations.

The preference is decidedly for the common neutral return where existing current transformers are used. This is the practice of six companies reporting 155 installations as compared to three companies reporting 20 installations, which make use of insulating current transformers in the individual neutral circuits. No nonmagnetic conduit is used in any installation.

Proposed installations of this type favor the use of existing current transformers and are quite evenly divided between insulating current transformers and the use of the common neutral return.

A very general freedom from open-circuit current-transformer troubles is indicated by the fact that 19 companies reporting 464 installations find it unnecessary to make any provision to check for this condition, except by reading the various currents at the time of the periodic relay check.

Three companies reporting 124 installations make use of fault detectors in series with the differential relay. This permits of an alarm indication in case the differential relay alone should operate due to an open current transformer.

Three companies reporting 197 installations use one-ampere ammeters in the neutral circuits which are read three times daily. A similar check is made by one

company using the harmonic-restraint type of relay by means of a low-reading high-resistance a-c voltmeter connected across the internal current transformer of the relay.

Twenty companies reporting 640 installations test for a short-circuited condition in the current transformers at the time of the relay check, usually annually. The procedure is divided between the companies which read load current values in the various branches of the differential circuit and the companies which apply an external voltage to determine the impedance of the circuit.

One company reporting 110 installations applies to the relay daily a potential which is too low to cause it to trip. The value of the resulting current will determine an open- or short-circuited condition. Another company reporting 11 installations makes a monthly tripping test with a small transformer just adequate to trip the relay under normal conditions.

Five companies reporting 51 installations make no check for short circuits following initial installation.

(*b*) *Differential Relays.* Phase differential relays are usually set above maximum load current of any circuit, according to 13 companies reporting 531 installations, and settings range as high as three times this value. Seven companies reporting 63 installations set phase relays below maximum load values.

In the case of neutral relays, the situation is reversed with 2 companies reporting 17 installations with settings above the maximum load and 11 companies reporting 413 installations using settings below this value.

Considering both neutral and phase relays which are set below maximum load values, 12 companies reporting 343 installations find it unnecessary to make any provision to prevent tripping due to accidental opening of a current transformer. On the other hand, six companies reporting 98 installations use fault detectors in series with differential relays to prevent the occurrence of faulty trippings on this account, and one company uses percentage differential relays for the same purpose.

Both schools of thought find results satisfactory since the majority of the proposed installations involve no change in practice.

Percentage differential relays are employed in 107 installations reported by 13 companies. Considerable diversity of opinion exists as to the most desirable grouping of current transformers.

Four companies reporting 77 installations group sources to one winding of the relay and loads to the other. This number includes the largest user of percentage differential relays for bus protection, a company with 66 installations. Similarly two companies with 7 installations use three-winding differential relays and group sources to one winding, loads to another, and bus ties to the third.

Two companies with 11 installations connect the principal source or sources to one winding and other sources and loads to the second. One company with 4 installations groups both sources and loads to each winding. Three companies with 5 installations include transformer banks in the differential protection and naturally group current transformers according to potential of the bank windings.

(*c*) *Prevention of Relay Operation on Transients.* Eleven companies reporting 483 installations make no intentional provision to prevent operation of the differential relay on through faults due to transients set up in the differential circuits by iron saturation in the current transformers. It is of interest to note that all of this group with the exception of two companies reporting 238 installations make use of induction relays which inherently introduce some time delay.

The largest user of instantaneous relays for bus protection, reporting 182 installations, keeps the ratio of fault current to current transformer rating within the conservative limits of ten to one. This should be of considerable assistance in providing for an iron-saturating transient. The remaining 16 reporting companies make provision for this factor in a number of ways.

Ten companies provide time delay in one form or another. Three companies use high relay settings while three companies provide high capacity or special transformers. Transient shunts are in use by one company and the harmonic restraint type of relay is installed for this purpose by another.

(*d*) *Effect of Abnormal Setups on Protective System.* As to means provided to maintain the effectiveness of bus protection when the "normal" circuit setup is temporarily changed, practice is evenly divided on the need for such protection. Fifteen companies report 362 installations with no provision for this eventuality. Comments from this class indicate that many remove entire groups of equipment from service for maintenance and others include current transformers from all possible connections. Other companies operate with inadequate protection if the weather is favorable.

Eight companies reporting 187 installations follow the practice of opening the trip circuit of the differential relay manually in case of an abnormal setup.

A small group of three companies reporting the substantial number of 249 installations use auxiliary switches on disconnecting switches which operate to open the trip circuit of the differential relay in case the normal switching setup is disturbed. In some cases one company switches current circuits to rebalance the protective system for the abnormal setup.

An interesting treatment of this problem is provided at one high-capacity generating station. Ten generator and step-up bank units feed into the 110-kv bus. Considerable flexibility is required for various combinations of units and outgoing lines. Each section of the double bus system is split into independent sections of variable lengths. To provide protection for these varying numbers of busses, the currents of all units and outgoing lines are combined through a differential overcurrent relay. The operation of this relay applies potential to a tripping bus. The individual switches on the incoming and outgoing feeds are then tripped by the individual phase and ground fault detectors with the potential from the tripping bus, thus making the protection independent of any possible grouping of circuits. An operation of the differential relay alone provides an alarm.

Fault Bus Protection

Most of the existing installations were built integral with the station. Eight companies so report 75 installations. Four companies report 35 installations added later. Three companies with a large group of 70 installations specify both categories without providing a detailed breakdown of the installations.

The preponderance of fault bus installations with special insulation is noteworthy. Four companies report 98 indoor installations and two companies report 26 outdoor installations with special insulation. Two companies report 8 metal-clad installations which naturally fall in this group. Natural concrete insulation is used by three companies reporting 45 indoor installations and two companies reporting 5 outdoor installations.

The importance of adequate insulation for satisfactory fault bus operation is obvious. In one case a group of 4 installations was discontinued and another group of 12 installations reinsulated after a series of faulty operations due to inadequate insulation.

Practically all installations are tested initially with various high voltage and current values. Seven companies report 165 installations which are checked for in-

sulation in periods varying from four months to two years. Where the insulation is high a high-voltage test is made and where it is relatively low a check of the current through the relay is made and compared with the total supplied at the test point. Two companies reporting 20 installations make no regular insulation tests.

In all cases the setting of the relays is based on the minimum anticipated fault current, together with a desirable factor of safety. In some installations using natural concrete insulation it has been found necessary to determine the percentage of fault current which appears at the relay for the various faults.

For similar reasons it has been found necessary at times to determine the maximum stray currents flowing through a relay for faults in adjacent sections in order to provide a setting in excess of this value.

Although two cases of faulty operation have been experienced due to accidental contact of low-voltage circuits, in general, this eventuality is not considered to be a serious hazard and no provision is made for preventing relay operation under this condition.

As a whole, experience with fault bus installations is considered satisfactory and further applications are in order for the reporting companies.

This approval is qualified for one group of 4 installations which were decommissioned because of inadequate natural concrete insulation. Another group of 12 installations was reinsulated after a series of faulty operations and are now scheduled to be changed over to a combined differential and fault bus scheme. It is thought that future installations would be of this order.

A number of companies experienced insulation difficulties with initial installations of the fault bus system, but felt that the condition was now satisfactory and that additional installations are in order.

Partial Differential Protection

Where distance relays are utilized, these are of the impedance type, employing wye-connected currents and phase-to-phase voltages for protection against phase faults or phase-to-neutral voltages for protection against ground faults.

Fault detectors are used in practically all installations. These consist of instantaneous overcurrent phase or ground relays, residual-voltage relays, and polyphase directional or directional ground relays polarized by station neutral current.

No especial difficulty is apparently experienced in providing an adequate safety factor in the settings of the impedance relays if arcs of reasonable lengths are considered.

Special Bus Protective Schemes

Two companies propose to install bus protection by a scheme based upon the "directional comparison" method of pilot protection of lines. The scheme provides a directional ground relay on every bus tie and feeder and an overcurrent relay in the neutral of the generator. The tripping is initiated by the operation of the neutral overcurrent relay and the trip circuit is routed in series through the front contacts of all directional relays on incoming circuits and the back contacts of all directional relays on outgoing circuits.

If the outgoing circuits have no source of ground current backfeed, overcurrent relays may be substituted for directional relays.

One company reports seven installations in which both incoming and outgoing circuits from the bus are provided with impedance relays. The incoming impedance relays are provided with a slight time delay and can be kept from functioning to trip all incoming circuits by the operation of the instantaneous impedance relays on the outgoing circuits.

General Considerations

(*a*) *Hazards of Inadvertent Relay Operation.* Twenty-nine reporting companies believe that the advantages to be obtained from bus protection are adequate to justify the hazard of an incorrect operation. Two companies feel that no possibility of load loss should be incurred.

A large majority of existing installations are arranged to trip on the operation of any differential relay alone. This group includes 850 installations reported by 23 companies. Ten companies report 65 proposed installations in this classification.

Ten companies reporting 288 existing installations require or favor the use of some checking device such as a fault detector which must operate in addition to the differential relay before tripping can be accomplished. Twenty-three proposed installations reported by four companies will likely be in accordance with this policy.

One installation on an important 230-kv application makes use of two completely separate sets of differential protective equipment, including the current transformers. Both sets of relays must function to clear the bus. Either set operating alone will provide an alarm only.

The requirement of this safeguard appears universal with the partial differential type of installations.

A preponderance of existing and proposed installations favor the use of a single multicontact relay for tripping as opposed to the use of a separate auxiliary relay for each switch tripped. Twenty companies report 757 installations following this practice while 11 companies reporting 437 installations use a number of auxiliary trip relays. Among some of these latter companies it is evident that the consideration involved was not a matter of principle, but the fact that a preferred type of auxiliary relay did not have a sufficient number of contacts in a single unit.

(*b*) *Supervision of Trip Circuit.* About one-half of the companies reporting on about two-thirds of the installations use supervision of the tripping circuit through the differential relay and the remainder do not. It is probable that many of the latter did not consider the supervision of the trip circuit of the oil switch alone as belonging to this classification and it is certain that a considerable number of the former group did include these cases.

Several companies use complete supervision of the differential trip circuit if it is routed through a number of relays or through interlocks on disconnecting switches.

(*c*) *Equipment Tripped and Locked Out.* The common practice is to trip all switches on the bus, as 25 companies so report 895 installations. Six companies reporting 107 installations trip all feeds to the bus only. Two companies reporting 22 installations trip only the major feeds to a bus.

One company reporting 13 cases of partial differential protection for ground faults trips only the sources of ground current feed to the bus.

The last three companies referred to also report 220 installations which were included in the first group with all switches to be tripped.

Breaker closing circuits are not generally locked out by the operation of differential relays. Twenty-four companies with 796 installations report against this practice. However, out of this group, eight companies with 407 installations use hand reset auxiliary relays and since relays of this type are commonly used in oil-switch control practice, it is probable that many other similar cases were not considered within the scope of the question.

Six companies reporting 107 installations follow the practice of locking out the breaker closing circuit with a differential relay operation. Three companies allow

one or two reclosures at automatic substations so equipped prior to lockout.

(*d*) *Hazards of Interconnected Current Transformers.* The necessary interconnection of current transformers usually involved in any bus protective scheme is not considered a hazard by 20 companies reporting 839 installations.

Nine companies reporting 341 installations believe such a hazard exists, but that it may be mitigated with insulating current transformers in the opinion of five companies with 139 installations and by separate current transformers according to two companies reporting 186 installations.

The danger referred to consists of an accidental contact of the balance circuit with high voltage and the possibility of false tripping incurred in the testing of the interconnected equipment. Several companies believe the hazards will exist in any case.

Twenty companies reporting 883 installations use independent current transformers for bus protection. Twelve companies report 133 installations where current transformers are used in common with other equipment. Three companies report 196 installations in both categories.

(*e*) *Backup Protection.* Backup bus protection is universally favored where full differential protection is not warranted. Twenty-eight companies reporting 1,011 installations are in favor of this practice while three companies with 52 installations do not follow it.

Opinion is evenly divided on the desirability of using backup protection in addition to full differential or fault bus protection. Sixteen companies reporting 500 installations follow this practice while 12 companies reporting 420 installations do not. Five companies report 285 installations in both categories.

Conclusions

From the factual data and discussion presented, the following conclusions may be drawn.

1. There is conclusive evidence that operating companies have generally accepted the idea of providing some type of protection for busses in installations of major importance.

2. Adequate bus protection can be obtained by any of the three major methods described.

3. Maintenance of bus differential relay systems is in general no different from that of other protective relay systems.

4. While complete current differential protection is predominantly the favored method, a number of apparently successful protective schemes have been developed which are applicable to old installations, and which avoid the excessive expenditures which would otherwise be required for complete current differential protection.

5. The considerable number of installations of fault bus protection reported, particularly as applied to existing installations, contradicts the general belief that this method of protection is limited to special cases specifically designed for the purpose.

6. While considerable complexity has been introduced into the protective scheme in certain cases in order to prevent inadvertent tripping of the bus, there is considerable opinion to the effect that such refinements are unnecessary.

7. While opinion favors the use of separate current transformers for bus differential protection, it is apparent that current transformers in common with other equipment can be successfully used.

8. When instantaneous or high-speed differential relays are employed, special care should be taken to prevent the operation of the relays due to transients.

Discussion

E. H. Bancker (General Electric Company, Schenectady, N. Y.): While the factual data are interesting in indicating what is in use and in showing that there is a considerable amount of bus relaying in existence, it should be borne in mind that not everything being done is what should be done in the future. A tire worn to the cords may never have blown out before but if used long enough it will. To illustrate, take the practice of grounding differential-current-transformer secondaries at all current transformers versus at one point only. Safety rules may make the multiple grounds desirable but freedom from falsely tripping a bus from potential gradients around the station dictate a single ground. It may be years before a case of false tripping appears, but it is quite probable that in most instances the single ground was selected by those companies using it because multiple grounds gave trouble. Just one case of trouble will change the practice of the company having it. So it is with some of the other procedures in which there seems a diversity of practice. Hence in utilizing this report it is highly desirable to apply some intelligent sifting process to determine which of several courses is the better.

W. K. Sonnemann (Westinghouse Electric and Manufacturing Company, Newark, N. J.): This report presents an interesting résumé of design, application, and operating data on the three principal means for obtaining bus protection at the present.

The report indicates that a great deal of thought has been spent on the problem from the standpoint that, in most cases, each bus presents its own particular problem. This is true because of the great variety of factors present, and we believe that it will continue to be so for some time to come.

The operating records shown are somewhat disappointing in that they indicate a rather high percentage of incorrect operations. However, if we deduct those false operations attributed to incorrect wiring, errors in testing, improper application, and the like, all of which should tend to disappear from the picture as experience is gained, the record looks more favorable.

The problem of the adverse effects of d-c transients is one which has not always been thoroughly appreciated in the past, but which is now receiving increasing attention. "Several" false operations are attributed to d-c transients, and it is quite probable that the most of these were associated with the generating station busses, approximately 30 per cent of the total installations. The solutions presented in the paper are interesting and represent solutions designed to fulfill particular operating conditions and protection requirements. Where high-speed operation is desired, the solution of introducing time delay is not possible, of course. In such a case, the proper co-ordination of current transformer performance together with the relays applied must be given the most careful consideration. It is felt that much is yet to be learned where time of relay operation of from one to three cycles is desired.

G. B. Dodds (Duquesne Light Company, Pittsburgh, Pa.): This paper contains a wealth of information on present practices regarding bus differential installations and several interesting conclusions can be drawn from it.

With respect to the ages of the type *A* differential installations which the report lists as having been in use for 11 years, it is wondered if a mistake has not been made in the length of time and that it possibly should be 21 years instead. It is known that in the company with which the writer is associated, bus differential installations were in use as early as 1924 and it is possible that other companies had them in even earlier.

In regard to the number and causes of incorrect operations, it is felt that the number as given does not constitute a bad record considering the number of installations in service and the length of time they have been in service, even taking into consideration that it is known that the number is inaccurate and probably should be increased.

Consideration of the causes reveals that a number of them could have been prevented by more thorough checking after installation and others by better maintenance. The record of performance for the ensuing years should be better than the past because of increased attention being given to this type of installation and interchange of ideas as provided by this paper.

It is interesting to note the diversity of design features used by the different companies and also that each company seems to be well satisfied with its own methods of installation. In other words, they have been able to solve the problems that have arisen in a manner that is suitable to them.

J. H. Neher: While relay engineers are agreed that from a protection standpoint some form of bus protection should be applied to all busses of major importance, nevertheless the relative infrequency of faults on protected busses requires serious consideration in connection with the economic justification of any such installation.

Based upon the data obtained from the questionnaire which represents the experience of a probable minimum of 5,000 bus-section years of operation of bus protective systems, only one out of every $3^1/_2$

Study of the Performance of the 3,600-Horsepower New Haven Electric Locomotives

By FELIX KONN
MEMBER AIEE

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IN June 1938, the New York, New Haven and Hartford Railroad placed in operation six new 3,600-horsepower a-c d-c passenger locomotives of the same general type as the ten 2,800-horsepower engines which were put in service in 1931, but incorporating numerous improved features to give considerably increased performance to meet the more exacting demands of modern high-speed transportation.

Motive power equipment, for the electrified main-line service of the New Haven Railroad, presents many problems, decidedly different from any other metropolitan district railroad electrification in this country, which are of interest to the design and to the application engineer. It is the purpose of this paper to point out the special requirements that had to be met, to give a brief description of the locomotive and of its equipment and to show by records of service tests how the engines are applied.

New Haven Requirements

The new locomotives were designed primarily for operation in the New Haven's normal express passenger service, as represented by a maximum duty of 1,200 tons trailing (15 80-ton Pullman cars) between Grand Central Terminal or Pennsylvania Station, in New York City, and New Haven, Conn., with three intermediate stops.

A-C D-C Operation

From Grand Central to Woodlawn Junction, about 12 miles, operation is over the New York Central's 660-volt d-c third-rail system. From Woodlawn to New Haven (60 miles), power is supplied from an 11,000-volt single-phase overhead contact system. Trains are operated also from Pennsylvania Station to New Haven (75 miles) over the Hell Gate Bridge route, operating on an 11,000-volt single-phase supply throughout. The requirement of third-rail operation necessarily complicated the equipment as combination a-c d-c units had to be provided.

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Axle Loading Restrictions

The Park Avenue Viaduct in New York City presents another problem in the design of New Haven locomotives. This structure has specially restrictive loading limitations which could not be exceeded.

Speed Restrictions

Numerous speed restrictions which are necessitated by junctions, drawbridges, and curves, make the demands upon the equipment more than ordinarily severe by requiring many accelerations. An examination of the speed charts for express service between Pennsylvania Station and New Haven, included in this paper, shows the saw-tooth nature of the resulting operation.

Grade Operation

From a grade standpoint, the Hell Gate Bridge route to the Pennsylvania Station is more severe than the run over the New York Central tracks to the Grand Central Station. On the eastbound run over this route the road climbs from 75 feet below sea level in the East River Tunnel to 150 feet above sea level over Hell Gate Bridge within a distance of 5.6 miles, equivalent to an average grade of 0.76 per cent and with a maximum grade of 1.50 per cent. Westbound over Hell Gate, there is a uniform average grade of 1.18 per cent for two miles.

Seasonal Variations

The New Haven's passenger traffic is markedly affected by seasonal conditions. During July and August, week-end travel to the summer colonies on Long Island Sound puts heavy demands on the local service between New Haven and New York, while at the same time through traffic is boosted greatly by the vacation movements to New England.

New Locomotives

It will be realized, from these special conditions of the New Haven system, that the new locomotives had to be suitable for:

Severe normal duty
Still higher seasonal peak duty
A-c d-c operation
Limited axle loading

To meet these conflicting requirements, it was imperative that advantage be taken of every possible increase in material utilization to realize the maximum performance possibility of the locomotive.

reported installations has experienced an operation and 22 per cent of these have been incorrect.

Messrs. Sonneman and Dodds have commented on this operating record which would seem to be very disappointing. As they have pointed out, in a large number of cases the reasons given for incorrect operations are such that if proper care had been taken in making and maintaining the installations, these operations would not have occurred.

In regard to the matter of incorrect operation due to transients, it must be realized that the present intense interest in such matters is only a little over a year old, and was just starting at the time that the questionnaire was circulated. It is reasonable to assume therefore that when fuller knowledge is available in this respect, a number of changes will have to be made in existing installations of bus protection.

Mr. Dodds has questioned the figures given for ages of the various types of protective systems. We wish to point out that the word "average" was unintentionally omitted in this connection. The figures given represent average ages computed on the assumption that all installations of the same type reported by any company were in service at the earliest date reported.

Mr. Bancker's point in respect to the use of multigrounded current transformers is well taken and although no incorrect operations were reported as a result of this, nevertheless it seems that this practice should be avoided.

In conclusion we wish to express our thanks to the engineers of the 34 reporting companies who filled out the rather long questionnaire and particularly to Mr. Tesar of the Cleveland Illuminating Company who examined the returns and compiled the data on which this report has been based.

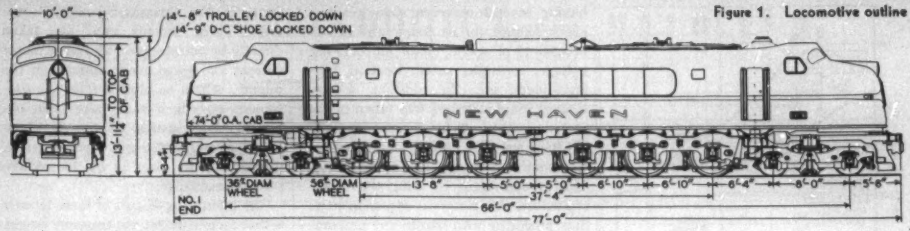


Figure 1. Locomotive outline

Performance Capacity

Whereas the continuous capacity of the new locomotives is only 800 horsepower greater than that of the 0351–0360 engines, their peak output of 7,600 horsepower exceeds by 2,800 horsepower the corresponding figure for these earlier engines.

This considerable increase in peak performance capitalizes this most important asset of electric locomotives in general: their ability to draw abundant energy from the external power supply and transform it into excess performance by virtue of their overload capacity. This permits handling loads in excess of normal, on certain trains, without alteration of schedule time and, within limits, without detracting from the life of the equipment.

Because of this intermittent character of the maximum service, a locomotive designed specifically to handle the peak load continuously would be larger, and more expensive than warranted. On the other hand, to assign locomotives continuously to duty demanding more than their normally rated capacity is a questionable application, although it is being done deliberately in some cases with older equipments and with apparent success. However, to take advantage of the overload capacity of a locomotive to handle infrequent peaks, is unquestionably justified and allows realization of the maximum usefulness of a given locomotive.

The overload capacity of these electric locomotives is also normally used in everyday service to maintain high schedule speeds by quickly accelerating the train to the maximum permissible speed after slowdowns.

This is brought out in figure 2 which compares the maximum performance characteristic of these new engines with that corresponding to 3,600-horsepower axle output. The shaded area, representing extra capacity made available to the electric locomotive by the external power supply, will increase two- to threefold the rate at which the train will be brought back to top speed, thereby procuring faster service and a better utilization of the track capacity.

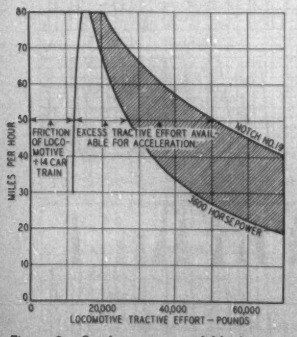


Figure 2. Surplus power available for rapid acceleration

Heating and Commutating Capacity

The ability of the generating, transmission, and contact system to supply the surplus power required for peak performance, must be matched by the ability of the locomotive equipment to transform it efficiently and reliably into mechanical energy. To this end, adequate heating capacity has been provided in all parts of the electrical equipment. Also, ample commutating capacity has been built into the traction motors so that they can transmit these high outputs without excessive duty on the commutators and on the brushes. In fact, the consideration of commutation influences the design and determines the size of the traction motors to a far greater extent than the heating capacity requirement, because the commutating capacity is largely determined by the fundamental constants of the motor, while the heating capacity can be increased by the use of more ventilating air. Thus, conservative commutating conditions can only be secured by conservative design constants and the six twin-armature 12-pole traction motors with which these locomotives are equipped, are especially favored in this respect.

Control of Commutating Performance

With the basis thus laid for safe commutating conditions, special attention was given to obtaining an accurate control of the traction motor commutation throughout the entire load range.

Reduced exciting field strength is used in the new locomotives to minimize the sparking at starting, up to approximately ten miles per hour, at which speed the exciting field shunt is disconnected by the action of a phase-angle type relay.

Two commutating field settings are available in the new locomotives as in the earlier 0351–0360 units, but a new connection of a phase-angle type relay was developed to control the changeover from the low-speed to the high-speed commutation setting. The performance of this relay is truly matched to the motor. It ignores such variables as line voltage and wheel diameter and its internal characteristics insure that the change in commutating field connection is determined solely by the two factors, current and speed, which together determine the commutating condition, thereby resulting in the minimum commutator and brush maintenance.

To further insure as complete a control of commutation as possible, three indicating lights are provided, which light up in sequence as the various field contactors function and thus furnish the operating crew with a continuous check on the correct performance of the motor control equipment (figure 3).

Finally, periodic inspections and gradings established by the appearance of the commutators provide a timely warning in case some abnormal conditions might tend to increase the commutation duty.

Ventilation

With the size of the traction motors largely determined by considerations of commutation, the amount of ventilating air was fixed by the requirement of meeting the 3,600-horsepower continuous rating of the locomotive and this, in turn, determined the pressure available for the ventilation of other parts of the equip-

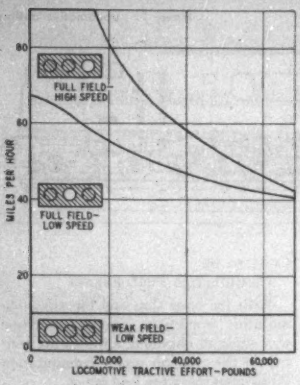


Figure 3. Operation of indicating lights

ment. Out of the total amount of air required on the locomotive, the traction motors use 61 per cent and the transformer, the blower motors, and the motor control units divide the remaining 39 per cent.

Because the ventilating horsepower requirement increases as the third power of the amount of ventilating air, it is very important that the amount of air to be supplied to each piece of equipment be accurately determined and adjusted.

Commutator-Type Blower Motors

Commutator-type blower motors as used on the New Haven locomotives are especially favorable to a close adjustment of the ventilating horsepower. They can be designed for the most suitable blower speed and the availability of various voltage taps on the transformer secondary gives the possibility of a final adjustment after all the equipment is tested and assembled. Commutator type blower motors also lend themselves to considerable energy savings by being operated on a lower voltage tap at a reduced speed, consequently at considerably less power, when full ventilation is not required. Thus, when the New Haven locomotives are energized but idle, the blower speed is reduced by 30 per cent resulting in a 65 per cent saving in blower kilowatt demand.

Service Tests and Records

Shortly after these locomotives were delivered, a series of road tests was conducted by the New Haven Railroad to verify performance in revenue service or with special test trains operating on regular passenger schedules.

Very complete records were secured by having several observers take readings every minute (or as frequently as was necessary) of speed, motor current, line voltage, controller notch, location, kilowatt-hours, etc. In addition, a continuous graphic record was taken of the motor current, which was used throughout these tests as a measure of the locomotive tractive effort available at the wheels. This is equivalent to using the series-excited traction motors as dynamometers, thus procuring with hardly any preparation an accurate record of the locomotive tractive performance.

Since the train speed variations take place gradually, it is possible to obtain a very good record of it without a recording instrument. With these two records, tractive effort and speed, synchronized by timing watches, the locomotive horsepower can be readily plotted as shown on the accompanying charts.

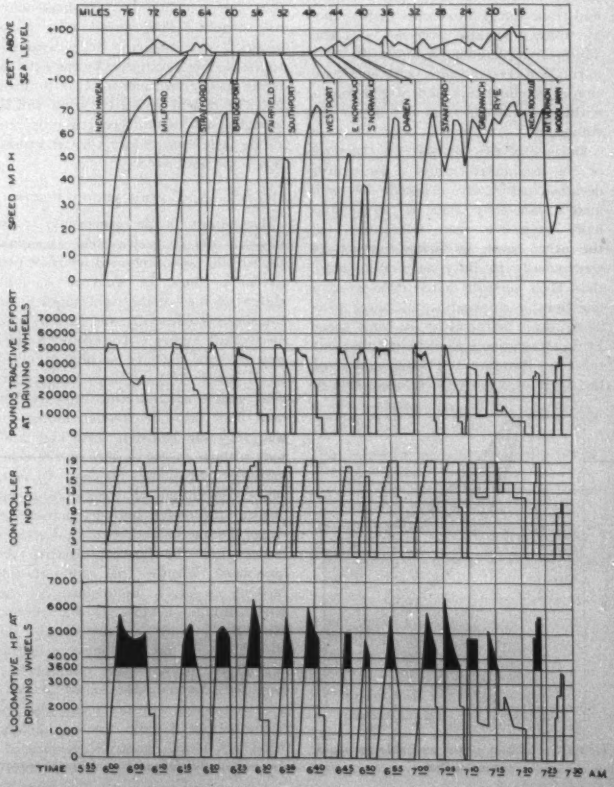
The same data have been plotted in a condensed, but perhaps more striking form, in the "minute-by-minute" records. These records can be taken directly by one observer, who reads motor current and speed every minute, on the minute, or can be plotted from the continuous records if such have been obtained. Each double reading is transcribed as a speed-tractive effort point, which takes its place in the locomotive performance range.

The interesting feature of these records is that each little dot has the same weight as any other little dot, in so far as the time element is concerned and any grouping of points indicates a zone where the engine is operated a large fraction of the time.

Records in both the continuous and the "minute-by-minute" form are shown for

Figure 4. Continuous record, train number 367 with 15 cars, New Haven to Woodlawn

Blackened areas show use of horsepower in excess of continuous rating



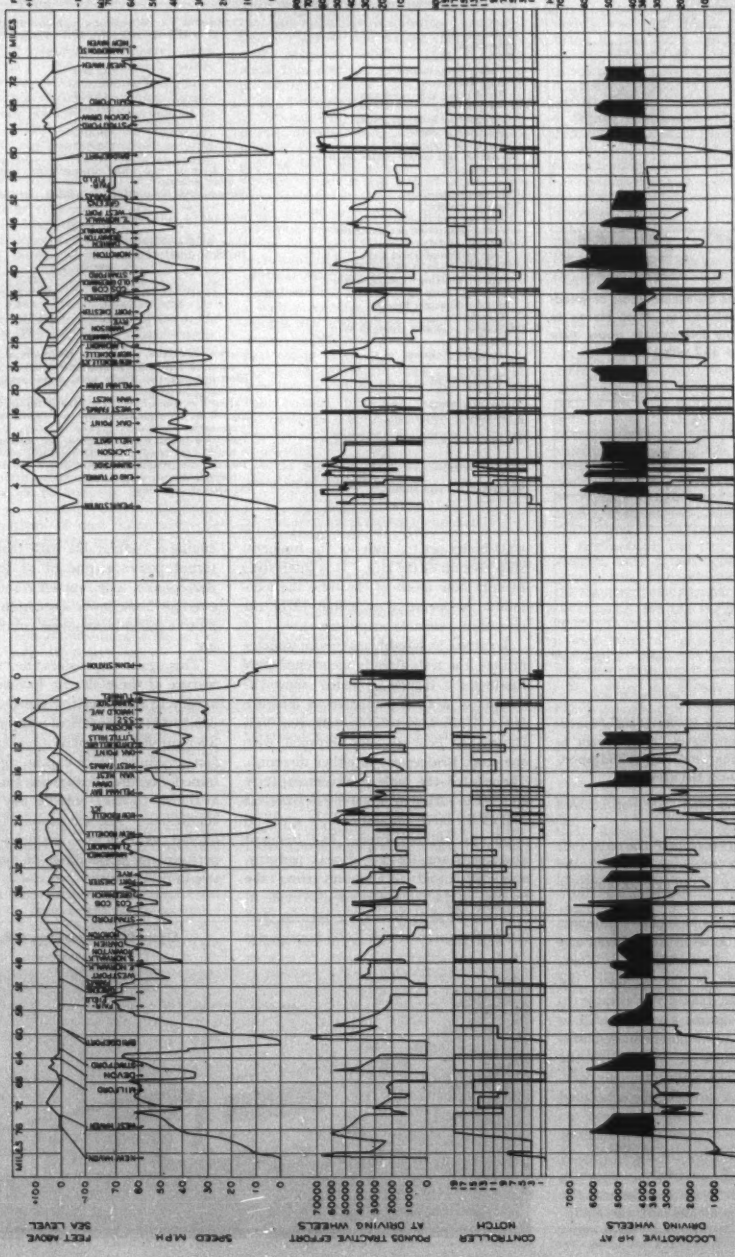


Figure 5. Continuous record, 80-car test train

Blackened areas show use of horsepower in excess of continuous rating

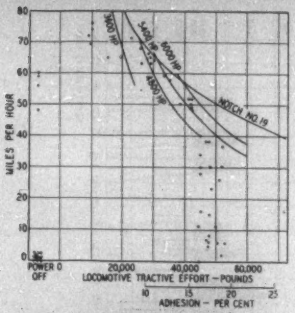


Figure 6. Minute-by-minute record of speed-tractive effort performance, New Haven to Stamford with nine intermediate stops, train number 367 with 15 cars

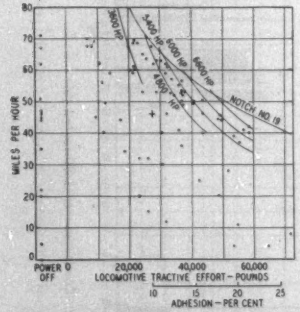


Figure 7. Minute-by-minute record of speed-tractive effort performance, New Haven to Pennsylvania Station* with stop at Bridgeport, 20-car test train

* Readings beyond Hell Gate not included

two trains which emphasize the outstanding performance made possible by the overload capacity of the new locomotives (figures 4 to 7).

Train No. 367 is a high-class commuter train, operating between New Haven and Grand Central Terminal, New York. On certain days in the summer, the amount of traffic makes it desirable to handle 15 cars against a normal of 8 to 12 cars. This peak requirement demands that the locomotive be operated at the equivalent of 22 per cent continuous overload for one hour to meet the scheduled time.

Figures 4 and 6 show the records of such a run, illustrating the use of reserve horsepower and overload capacity. Operation of this sort is approaching the performance of multiple-unit car equipment, energy consumption being 60.5

Table I. 0361–0366 Locomotives for the New York, New Haven and Hartford Railroad

Type	11,000-volt a-c, 660-volt d-c high-speed passenger	
Nomenclature	2 − C + C − 2 432/270, 6*GEA622A*, 11,000/660 volt	
Dimensions	See figure 1	
Weights—pounds:		
Total—fully loaded	433,200	
On drivers	272,400	
Per driving axle—average	45,400	
On guiding	160,800	
Per guiding axle—average	40,200	
Mechanical parts	269,400	
Electrical equipment	163,800	
Maximum safe speed—miles per hour	93	
Running gear	2 − C + C − 2 wheel arrangement, cast steel trucks, plain journals	
Cab construction	Streamlined, double end, all welded, outside truss type	
Traction motors:		
Number and type	6*GEA622A* twin armature	
Volts—maximum per armature	300	
Method of drive	Gear, quill and spring cup	
Gear ratio and wheel size	78/23 = 3.39; 56 inches	
Tractive effort at 25 per cent ad.	68,100	
Locomotive rating—continuous:	A-C	D-C
Tractive effort—pounds	24,100	26,900
Speed—miles per hour	56.0	39.6
Horsepower	3,600	2,840
Maximum available horsepower	7,600	5,500
Control:		
Alternating current	Electropneumatic, single unit, three circuit, single motor combination with 19 running notches	
Direct current	Electropneumatic, single unit, series-parallel with two running notches	
Main transformer	Forced-flow forced-cooled synthetic-liquid type	
Ventilation	Forced to all equipment by two combination blower-cleaners	
Blower motors	Two two-speed a-c, one-speed d-c commutator type, forced ventilated, each with overhung control generator	
Compressors	Two a-c d-c commutator type, self-ventilated, 100 cubic feet per minute displacement each	
Train heating equipment	Oil-fired steam boiler	

watt-hours per ton mile for the frequent-stop portion of the run. It is interesting to note how much of the time the locomotive is operating on notch 19 or the maximum available output curve.

To arrive at suitable maximum tonnage ratings, the tests already mentioned were conducted. Figures 5 and 7 show the records of a train composed of 20 Pullmans, 1,756 tons trailing, between New Haven and Pennsylvania Terminal, with one stop, Bridgeport, in either direction. The use of the high available capacity above the rating of 3,600 horsepower, as well as the large amount of time spent on notch 19 will be noted. The frequent slowdowns and the use of peak performance for rapid acceleration from the bottom to the top speed are also evident.

It can be seen from these records that the performance of this 3,600-horsepower engine is comparable with that of an internal power engine of at least 5,400-horsepower axle output, and yet the average horsepower is within the locomotive 3,600-horsepower continuous rating.

This again emphasizes the outstanding feature of these electric locomotives, the ability to make use of the overload capacity of their electrical equipment to deliver surplus performance making possible fast schedules which can be rigidly maintained because of the margin of power available to take care of any abnormal conditions. The accompanying data are offered as concrete examples of these performance possibilities of modern electric motive power.

Figure 8. Locomotive with train

Discussion

Sidney Withington (New York, New Haven and Hartford Railroad Company, New Haven, Conn.): This interesting paper presents the importance of qualifying electric locomotive horsepower rating figures to co-ordinate them with the service to be performed by the equipment. The quantity given in the paper indicating a maximum horsepower of 7,600, while undoubtedly permissible on such service as that of the New Haven, might well be too high a figure in connection with service on some other electrified territory.

The advantages in thermal capacity of the motors are obvious in this connection, in permitting short-time overloads. It is to be noted that in the overload rating of equipment under the circumstances described, the capacity not only of the main traction motors, but of the transformers, preventive coils, etc., must be taken into account. In this connection, a comparison of the characteristics of such equipment with the characteristics of the Diesel locomotive is of interest. A Diesel engine rated at 3,600 horsepower would have no overload capacity normally, and while the 3,600 horsepower would be generally available under all conditions, it could not be exceeded even for short periods. It is, therefore, impossible to compare, without qualification, the ratings of such locomotives as those described in the paper and Diesel-electric equipment.

The modern control for single-phase motors in providing excess voltage taps, permitting thus the utilization of increased horsepower ratings at higher speeds, is one of the most notable advances in the art of locomotive design in recent years.

E. W. Brandenstein (General Electric Company, Erie, Pa.): You have heard Mr. Konn tell us that these a-c locomotives are so designed, from a heating and commutating standpoint, that they will absorb the huge blocks of power furnished by the transmission and distribution system.

Now what do these overload capacities give us from a practical operating and economic standpoint? Mr. Konn has explained that the total number of locomotives required for passenger service depends upon a few peak days throughout the year. On those days the train length can be increased from, say, 12 cars to as high as 20 cars, thereby taking care of a possible 60 per cent increase in passenger traffic. That is not enough to accommodate passenger peaks which come on football days, holidays, inauguration, etc. To take care of these peaks, it is necessary to add many trains and locomotives in spite of the increase in train length from 12 to say 20 cars.

Here is a real traffic overload problem. A 60 per cent increase in train weight, with the same high schedule speed, is not enough. How are we to take care of the additional trains required without increasing the total number of passenger engines? I will tell you. This overload and commutating capacity solves the problem for us. We will resort to our freight locomotive pool for the additional passenger engines required. The peak freight traffic and peak passenger traffic do not, fortunately, come on the same day. "Oh," you will say, "you can't do that. In order to do a thing like that you must have a universal engine, one that is good for slow freight and also high-speed passenger traffic." That is exactly what this overload and commutating capacity does for us. Let me illustrate it.

The Pennsylvania Railroad have a group of 70-mile-per-hour engines which are purely freight locomotives. They have another group which are 100-mile-per-hour engines that are used only in passenger service. There is still a third group of 90-mile-per-hour engines which are used in either freight or passenger service, depending upon whether the traffic peak is passenger or freight. Last October, when there was a peak in freight service, a large number of these 90-mile-per-hour engines was in freight service. During the recent holidays, a high percentage of the 90-mile-per-hour engines was in passenger traffic. The same engines which were hauling 4,500 flat ton coal trains in October were handling the high-speed passenger trains in December. You can readily appreciate that these 90-mile-per-hour universal engines are responsible for a great decrease in the total number of passenger and freight engines required.

What does this high overload and commutating ability give us?

1. Faster schedules.
2. Heavier trains at these fast schedules.
3. A universal engine.

What does this mean from an operating and economic standpoint?

1. Fewer engines.
2. Lower capital expenditure.
3. Lower fixed charges by virtue of the lower capital expenditure.
4. Lower maintenance costs by virtue of fewer locomotives.

In other words, gentlemen, I believe this overload capacity for this type of motive power is completely changing the complexion of railway electrification.

P. H. Hatch (New York, New Haven and Hartford Railroad Company, New Haven, Conn.): One of the inherent features of electric equipment operating from an external power supply is the ability to operate for short periods considerably in excess of continuous ratings. There is nothing new in this, and the immediate extent to which such overload operation can be carried is usually limited only by weight on driving wheels and the ability of the electrical apparatus to stand the overloading. There is, however, a long term factor which may be decidedly limiting. This is the cost of maintenance. If overloading is carried to the point where its advantages are offset or exceeded by cost of additional maintenance, then the overload characteristic of electrical equipment can be a liability rather than an asset.

In the paper under consideration, the authors describe at considerable length instances of short-time overloading of the new locomotives, but except for rather general paragraphs on heating and commutating capacity, very little is said about the effect of overloading on maintenance of the equipment.

To make the story complete, it would be interesting to know specifically what has been done to obtain high overload capacity. With a locomotive of fixed maximum axle loading, was such capacity obtained by increase in ventilation, additional iron and copper, by improvement in design, or by a combination of any of these? Was a definite overload capacity planned on, or was the determination of this left for road tests or service experience? Has any relationship been established between overloading and life of apparatus, or is this, too, left for determination in service?

Providing the high overload capacity is not seriously at the expense of maintenance, it unquestionably has very great possibilities in the design of electric locomotives. These possibilities, it is believed, warrant a full and complete discussion of the means employed to obtain such capacity.

Felix Konn and **F. H. Craton:** We agree with Mr. Hatch that, from the standpoint of heating as a limitation, electrical equipment has always had overload capacity at speed. We wish to point out, however, that, in the single-phase locomotives which were built up to about ten years ago, full advantage could not be taken of this feature because the output of the earlier types of traction motors (of the resistance-lead or doubly-fed type) was decidedly limited by destructive sparking at the brushes, especially at the higher speeds.

To overcome this limitation, a new type of single-phase traction motor was developed, offering not only very favorable commutating characteristics (by virtue of the low flux made possible by a large number of poles), but also the possibility of controlling the commutating performance over a wide range of speeds and currents, especially at high speeds and high horsepowers.

As pointed out by Mr. Withington, the possibility of wide range control of the traction motor voltage which is fundamental in single-phase locomotives—but which had to be held in check with the earlier types of motors—found a vigorous outlet in the modern single-phase traction motors which permit the modern single-phase locomotives, in which full advantage has been taken of their inherent fitness for "overvoltage" and "overload" operation, to deliver the higher speeds and horsepowers demanded by progressive transportation.

Mr. Brandenstein has brought to your attention some of the tremendous service advantages of these modern engines which operators have been quick to recognize and to develop. The ample horsepower reserve and the inherent flexibility of this type of locomotive offer many more possibilities in faster schedules with heavier trains and fewer locomotives and the way is open for further advances for still better and faster service to the public and the industry.

In emphasizing the importance of qualifying electric-locomotive horsepower-rating figures to co-ordinate them with the service to be performed by the equipment, Mr. Withington has brought out a glaring deficiency in our present practice of rating electric locomotives primarily on the basis of their continuous capacity.

Undoubtedly the use of the continuous rating provides a very definite "yardstick" for one of the features which determine the

Continuous Processing for Automobile Tire Fabrics

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PROGRESS is evident to an unusual degree in the fabric-processing operations at the new automobile-tire plant of the Ford Motor Company.* The fabrics and rubbers which are run through these operations to form the rubber-fabric structures used in building the automobile tire pass through processes and machinery which clearly reflect the continuous production idea developed by the automobile industry. The electrical equipment in this plant introduces ideas which make the drives fundamentally different from those in general use.†

In these processing operations four types of rubber-fabric structures are produced: (1) ply stock, the material for the plies in the tire, (2) breaker strip stock, which goes between the plies and the tread, (3) chafer stock, used between the plies and the side walls, and (4) bead stock, from which strips surrounding the beads are made.

Fabric for the ply stock originates in a creel room from which 1,500 to 1,600 separate cords are guided from spools into parallel positions to form a broad sheet of cords without weft. Fabric for the breaker stock is the same as that for ply except that the cords are farther apart and the sheet, prepared at textile mills, is in the form of a woven fabric having a weft of very small threads. Fabrics for the chafer and bead stocks are special square-woven fabrics similar to duck in construction. From these starting points, these textile raw materials pass continuously through production lines and combinations of machines, as indicated in figure 1, to emerge as the four finished stocks.

From an electrical standpoint, the drives may be segregated into those for (1) main calendering operations, (2) bias-cutting operations in which the previously rubberized fabric is cut on the bias, and (3) slitting and coating operations in which some of the bias-cut material is slit into strips and further treated with rubber. The main calendering operations present most of the electrical problems associated with the several drives and these problems may, therefore, be

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* Because of the numerous advanced manufacturing ideas which it embodies, this $5,600,000 plant located at the Ford Motor Company's Rouge Plant, Dearborn, Mich., is of exceptional engineering interest throughout. Operations are designed to keep materials moving steadily forward from the moment the bales of crude rubber are cut up and started on their way through plasticators, mixers, mills, and so on, until the finished tires emerge from final inspection. A description of the complete plant is in the *India Rubber World*, June 1, 1938.

† Acknowledgment is made of assistance from E. F. Wait, J. T. Mortley, and A. J. Walrath of the Ford Motor Company in the development of these drives.

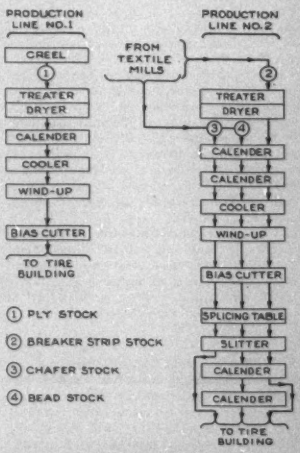


Figure 1. Diagram of sequence of processing operations

In production line number 1 the parallel cords from the creel are dipped in liquid rubber, passed through a dryer, and then through a four-roll calender which simultaneously adds rubber to both sides of the sheet. The calendered sheet passes through a cooler and then, with a liner to prevent sticking, is rolled up on a mandrel. The roll is transferred to a cutter where the fabric is cut on the bias and sent to the tire builders. In building up the tire the several plies are laid with the bias in alternate directions

In production line number 2 the fabrics pass through two calenders instead of one, the first calender working one side of the material and the second calender the other. The bias-cut material is spliced end-to-end on the splicing table. If the slit material passes through the final calenders a layer of rubber is laid on it at each calender

This paper discusses production line number 2 through the wind-up

value of an electric locomotive. So many of the other features (such as commutating capacity or overload capacity) are open to varying interpretations that it is very comforting to find in the continuous rating of an electric locomotive a feature which can be rigidly determined and which can form a definite basis of comparison.

However, the continuous rating should be supplemented by a service rating taking into account the peak capacity, say, 7,600 horsepower, of the locomotive which is more nearly representative of the amount of work which the locomotive can do than the continuous rating, say, of 3,600 horsepower.

Mr. Hatch has asked if a definite overload capacity is planned on. We will answer that the peak capacity of the locomotive is actually the most important factor in the design of the locomotive and that this consideration far outweighs the continuous capacity in the design of the various parts of the equipment.

To safeguard the use of the peak capacity in service, improvements in design and manufacture have been backed up by a careful system of checks in the testing, assembly, and servicing of these locomotives to insure, as much as possible, that, year in and year out, these equipments will deliver their high outputs under the conditions most favorable for the life of the equipment.

As a result of this increase in service capacity and of the efforts made to secure the best service performance, the modern single-phase locomotives are covering more and more mileage every year and with low maintenance cost per mile.

Mr. Withington also brings out the difficulty of comparing a Diesel-electric locomotive and an electric locomotive, both of which have a continuous rating of 3,600 horsepower measured at the driving wheels. The Diesel electric will deliver continuously 3,600 horsepower at the wheels and will never be able to exceed this output. The electric locomotive we have discussed will deliver 3,600 horsepower at the wheels continuously and up to 7,600 horsepower for short periods of time. The difference in accelerating performance between the two types of locomotive, which is illustrated in figure 2 of our paper, will be further emphasized by the greater weight of the Diesel electric locomotive which will require a greater part of its output for its own propulsion.

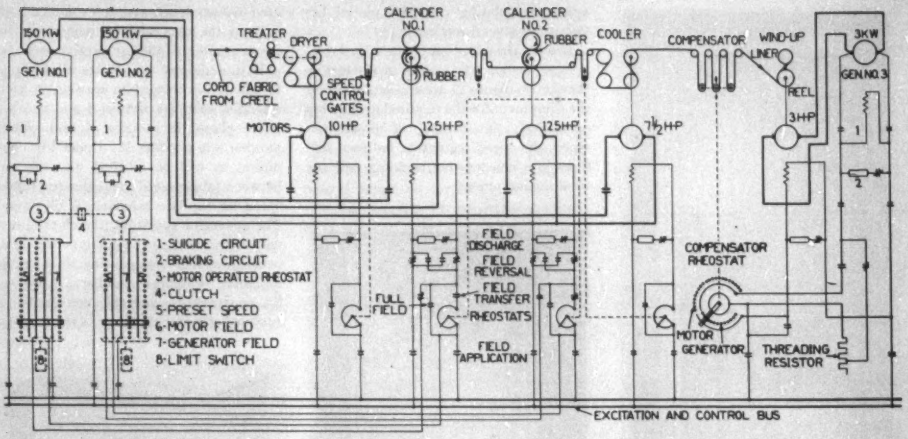


Figure 2. Schematic diagram of the armature and field circuits for the main calendering operations

described by considering one of the main calendering drives, schematically illustrated in figure 2.

Requirements of Main Calendering Line

The production speed to be 5 to 35 yards per minute with the design of the drive such that the top speed can be raised ultimately to 60 yards. Operation to be continuous at any speed within the range. While starting, stopping, and operating at any rate of production, positive and automatic speed regulation to be maintained between machine sections.

Equipment to be such that production combinations are available as follows: (1) material through the entire sequence of operations, or through this sequence with any one or more of the machine sections by-passed, (2) equipment operating as two independent drives, one drive consisting of calender number 1 and the sections ahead of it and the other consisting of calender number 2 and the sections following. In this setup, also, it must be possible to by-pass individual sections.

Equipment to be such that any combination of skim-coating or frictioning can be obtained on the calenders. By way of explanation, skim-coating consists of working rubber onto the surface of the fabric while frictioning consists of working rubber down into the structure of the fabric. The calenders have three equal-diameter rolls. The motor on each calender drives the middle roll which in turn drives the two outer rolls through gearing. The fabric passes between the middle and one of the outer rolls. When the middle and outer rolls are geared so that the roll surface speeds are equal, the fabric, which passes through the calender at the roll surface speed, is skim-coated. When the outer rolls are geared to rotate slower than the middle roll, say in the ratio two to three, the fabric takes the speed of the slower outer roll and is frictioned. Therefore, for a given fabric production speed, assuming a frictioning ratio of two to three, the driving motor operates 50 per cent faster when frictioning than when skim-coating.

Lastly, calenders to be reversible; quick stopping to be available during starting and running as a safety requirement; all control operations to be magnetic and to be actuated from simple controlling stations.

Constant or Adjustable-Voltage Drives?

Prevailing practice for calendering drives is to use adjustable-speed motors operated from a constant-voltage d-c plant system, frequently three-wire to permit doubling speed ranges by means of two armature voltages.

In the present instance, the adjustable-voltage or Ward-Leonard system of drive appeared to be particularly suited to the requirements. The smooth, relatively stepless, and rapid acceleration possible with this form of drive, the ease with which it lends itself to wide ranges in production speeds, its effectiveness where it is desired to maintain a controlled speed relation between separately driven machines, its flexibility in making the desired several combinations of the driven machines—all pointed to its adoption. In addition it offered an effective method of safety stopping, new to the rubber industry, namely, regenerative braking instead of the heretofore used dynamic braking.

A cost study of the two systems showed the adjustable-voltage system to be economically sound. In fact, a-c distribution and d-c adjustable-voltage drives proved less costly by an important margin than the common practice of d-c substation generation, d-c distribution, and constant-voltage drives.*

Driving Equipment

Most of the basic elements of the drive are shown in the sketch, figure 2. The generators are of standard shunt-wound construction, liberally rated and with a low saturation factor to enhance regen-

* It should be noted that this statement refers to a new plant in which economic questions are not influenced by existing equipment. With a constant-voltage system already established the same economic balance would not necessarily hold.

In the present instance, the cost of three-wire motor-generator sets, duplicated to insure continuity of service, high-voltage a-c switchgear, three-wire d-c switchgear and distribution, and constant-voltage driving motors and control were compared with that of high-voltage a-c switchgear, step-down power transformers, low-voltage a-c switchgear and distribution, and adjustable-voltage motor-generator sets, motors, and control. A two-wire constant-voltage d-c power system to take care of certain constant-voltage drives which would otherwise receive power from the main three-wire system was also included in the latter. No account was taken of possible differences in operating efficiency or improved production.

It may be of interest to note that having adopted the adjustable-voltage system, future expansion continues to be economical and, because of flexibility, is easily accomplished.

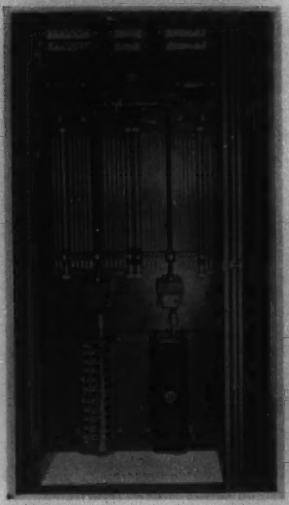


Figure 3. Motor-operated generator, calender motor, and preset speed rheostats with multiple limit switches and interconnecting clutch mechanism

erative braking and stable operation at low speeds. The exciter is compound wound and supplies all control-circuit power as well as excitation.

The motors are also shunt wound. They are selected with due regard to the fact that the adjustable-voltage drive is a constant-torque drive while the calendering operations require somewhat increased torque as speed is reduced. In the present instance full armature voltage is attained at approximately half of full production speed so that the drive is constant horsepower from full to half production speed and constant torque below half production speed. This results in a normal torque rating over the entire operating range that is amply above that required by the load. Due regard also is given to the relatively greater armature resistance of the small motors in that they are selected to have sufficient capacity to prevent them from breaking down at low armature voltages from this cause.

The control equipment consists of (1) main control board on which are mounted all the control elements that are not located at the drives, (2) master control stations placed at the calenders and at the wind-up for co-ordinated but independent control of the calendering and wind-up operations, (3) an operations set-up panel, and (4) "gate"-operated speed-relation regulating rheostats placed between the several sections.

Besides the adoption of the adjustable-voltage system, the points of interest in the sketch (figure 2) are the setting up of the equipment for the required production operations, the control of production speed, the speed regulation between sections, the regenerative braking, and the wind-up equipment.

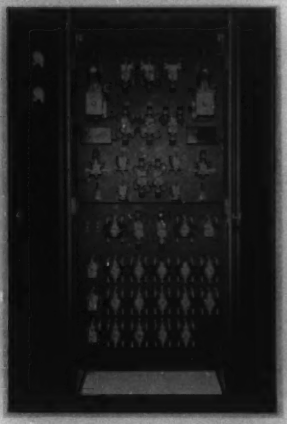


Figure 4. Typical main control panel. The relays on the bottom section control the setup operations of the rheostats, figure 3

Setting-Up Operations

To obtain the desired operating combinations, power is supplied by two independent generators. Figure 3 shows the two generator field rheostats with compound limit switches and with a clutching mechanism between the rheostats which permits independent or unit operation. Figure 4, which is typical of the main control panels, shows the rheostat setting-up relays. Figure 5 shows the master setting-up switches available to the operator.

Referring to figure 5, two of the switches control field contactors for forward and reverse operations of the calenders. Several other switches cut individual sections in and out of service. Three switches operate in the manner shown on the index plate.

Referring to the index plate, switch number 3 is placed in position *A* to operate the two calenders and their respective sections independently. In this position switch number 3 declutches the two generator rheostats so that they can be operated independently and, as explained later sets up the two calender motors as the master motors of their respective sections.

If it is desired to operate all sections together, say with skim-coating on each calender, switches number 1 and number 2 are placed in position *A* and switch number 3 in position *B*. Under this condition, as will be recalled, the relation between fabric speed and calender motor speed for the two calenders is the same. The generator rheostats, therefore, automatically position themselves to give equal generator voltages and then clutch together. Calender number 1 becomes the master motor and calender number 2 a following motor the same as the remaining motors. All of these setting up operations are automatically accomplished with the rheostat relays and rheostat limit switches.

Figure 5. Master operations set-up panel. The index plate on the panel gives the switching direction for the desired production operations

Index Plate				
24" Train		Switch Position		
Calender		Switch	Swi ch	Switch
No. 1	No. 2	No. 1	No. 2	No. 3
Single	Single	A or B	A or B	A
Skim	Skim	A	A	B
Fric	Skim	B	A	B
Fric	Fric	B	B	B
Skim	Fric	A	B	B
Complete train must be shut down before changing switch positions.				

Instead of the skim-coating operation on both calenders assume that it is desired to skim-coat on the first calender and friction on the second. Under this condition, calender number 2 must

operate faster than calender number 1, in the ratio three to two for the frictioning ratio previously assumed. The generator rheostats, therefore, position themselves before clutching so that the voltage of generator number 2 is higher than that of generator number 1 in the ratio three to two.

Control of Production Speed

Starting, stopping, and speed control of the drive are accomplished with a stop-thread-run-hold master switch and a preset-speed rheostat, figure 6. Stopping may also be accomplished from several switches located about the driven machinery.

With the master switch in the stop position, generator excitation is removed and the generator rheostats assume the minimum generator voltage position. Turning the master switch to the thread

Figure 6. Master control desk with starting and stopping control stations, speed preset rheostats, and tachometers

position applies field to the generators which brings the drive to minimum speed. During this operation, full field is maintained on all motors for a definite time to insure positive breakaway and starting. Turning the switch to the run position operates the generator rheostats to raise the generator voltages to full value and then to weaken the field of the master motor.

The speed to which the generator rheostats bring the drive is determined by the setting of the preset-speed rheostat. This rheostat has a companion rheostat of duplicate characteristics built into the generator rheostat units. The voltage drops across these two rheostats are balanced against each other and when they are equal, relays function to stop further travel of the generator rheostats. Thus, if the drive is stopped or slowed down, it will always return to the original production speed as determined by the setting of the preset-speed rheostat when the master switch is again turned to the run position.

At any time during the speeding up or slowing down of the drive, the speed can be maintained constant by turning the master switch to the hold position.

Upon stopping, the generator rheostats automatically assume the minimum generator voltage position. The rate of travel on the rheostats is adjustable for either direction. It is made fast on the down stroke to prevent delay in restarting after a stop.

Speed Regulation Between Sections

Either the motor of calender number 1 or of calender number 2 is the master motor, except when the calenders are operating independently, in which case both motors are masters. Whichever motor is the master determines the speed of production. Referring again to figure

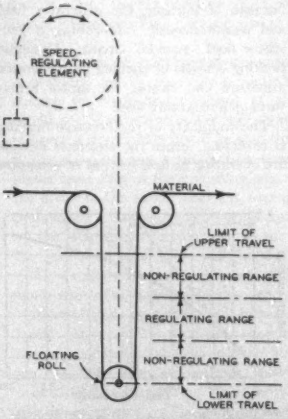
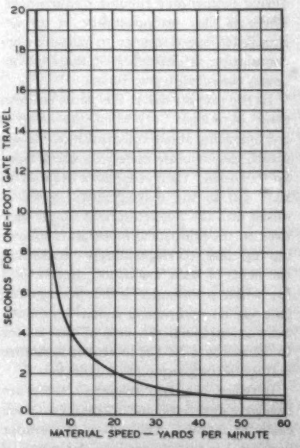


Figure 7. Schematic diagram of typical gate or dancer roll for regulating motor speed

2, it will be seen that the generator rheostats are also master motor field rheostats, that is, the master motor speed is first raised by increasing armature voltage with constant motor field and then further raised by decreasing motor field with constant armature voltage. In other words, the master motor must operate at the speed corresponding to the setting of its generator-motor rheostat.

All other motors are regulated to follow the speed of the master motor. This is accomplished by gates or dancer rolls which operate motor field rheostats. This form of regulation has been used for many years, particularly in the rubber and textile industries. It is discussed briefly here to show how well it works in connection with the adjustable-voltage drive and particularly where such a drive is operating in conjunction with speed control by motor field.

Figure 7 schematically illustrates a typical gate. Within its stops, the center roll is free to move up and down and in this travel it actuates the speed control element, in this case the field rheostat of the controlled motor. If the motor delivering material to the gate delivers ma-



Yards Output	Per Cent Difference 5	10	15	25	35	50	75	100
60	.3	.6	.9	.15	.21	.30	.45	.60
55	.27	.55	.82	1.37	1.92	.27	.41	.55
50	.25	.5	.75	1.25	1.75	.25	.37	.50
45	.22	.45	.67	1.12	1.57	.22	.33	.45
40	.2	.4	.6	1.0	1.4	.20	.30	.40
35		.35	.52	.87	1.22	1.75	.26	.35
30		.3	.45	.75	1.05	1.5	.22	.30
25		.25	.37	.62	.87	1.25	1.87	.25
20		.2	.3	.5	.7	1.0	1.5	.20
15			.22	.37	.52	.75	1.12	1.5
10				.25	.35	.5	.75	1.0
5						.25	.37	.5

Figure 8. Tabulation and curve to illustrate the stability of gate control

In the tabulation, for a given yards output and percentage difference in speed between sections the figure applying gives the yards output for 100 per cent difference in speed. For example: yards output 50, speed difference 10 per cent equals 5 yards output 100 per cent difference. From the curve eight seconds are required for one foot gate travel at 5 yards 100 per cent difference

terial faster than the material leaves the gate the regulating roll will be lowered and conversely, if it delivers material slower, the roll will be raised. In either event, this motion is transmitted to the regulating rheostat to bring the motor speed to exactly that required.

If the material to be worked has sufficient strength to permit passing through the gate without injury, if it will stand the required flexure, and if its surface can be permitted to come in contact with rolls or similar structures this form of regulation is one of the best. It is extremely stable as indicated in figure 8 but more important its storage capacity permits momentary differences in speeds of relatively large magnitude which is valuable during starting and stopping or during momentary running disturbances. There is also no possibility of an accumulated speed change to cause an accumulation or deficiency of material between the regulated sections.

In the present drive, the gates perform three functions: (1) when the drive is not operating above full armature voltage speed, they operate merely as speed regulators to hold their respective sections in step, (2) as the master motor speed is raised into the weakened field range, they take on the additional function of following up and correspondingly weakening the fields of their associated motors, and (3) when a calender is frictioning, the gate on its companion motor automatically strengthens the field of that motor to compensate for the increased armature voltage accompanying this operation.

Between the two calenders there are two gate rheostats, one operating on each calender motor. The motor of calender number 1 is the master and the motor of calender number 2 is regulated to follow it for all operations except when frictioning on calender number 1 and skim-coating on calender number 2. For this particular operation, the motor of calender number 2 is made the master because this motor is operating below maximum generator voltage after the motor of calender number 1 has gone up to weakened field speed. The generator and motor field rheostats do not produce an operating speed strictly proportional to their travel. When the two rheostat units are offset, the differences in characteristics of the offset positions are compensated for by the gate speed-regulating rheostat. Wide range regulation of the regulated motor is more effective in the weakened-field range than in the armature-voltage range and the regulated motor is therefore set for this condition by making the motor of calender number 2 the master.

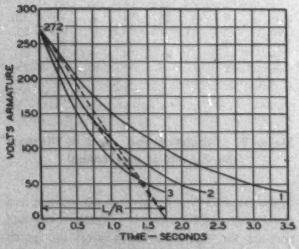


Figure 9. Typical field decay characteristics for 150-kw generator

For any armature voltage, inductance divided by field circuit resistance (L/R) is a measure of speed of field decay

Regenerative Braking

Regenerative braking was adopted instead of the customary dynamic braking because of its greater simplicity and because it produces as quick, if not a quicker, stop than by dynamic braking. Regenerative braking as referred to here consists of opening the generator field and simultaneously establishing a generator field "suicide" circuit. Dynamic braking consists of opening the generator armature and closing the motor armatures on a resistance load.

The simplicity of regenerative braking is twofold. Since the electrical devices are operating in field instead of armature circuits, they are simpler and less bulky. Again, as regenerative braking stops are so easily accomplished, all stops can be made regenerative braking stops and it is not necessary to design the controls for two forms of stopping as is customary in the case of dynamic braking when normal stopping is a coasting stop and an emergency requires a dynamic braking stop.

The regenerative braking stop also helps in another way. Since this system is applied to all stops, the several sections of the drive are brought to rest quickly and they therefore cannot depart far from their regulated positions with respect to each other. This, coupled with the fact that the adjustable-voltage drive quickly brings the sections into regulating range upon starting, results in an unusually effective speed-regulating system.

Neglecting the "suicide" circuit which is used to destroy residual and which may be considered as not affecting the results practically, the selection of generator characteristics for regenerative braking can be illustrated by the curves in figure 9. The rate of field decay is inversely proportional to the field inductance and directly proportional to the resistance of the discharge circuit. The instantaneous values of field current are a function of these two factors and the third factor—time. With these factors and the generator saturation curve, the expected performance shown in the curves can be calculated.

Having determined a reasonable inductance for curve 1, faster curves such as 2 and 3 can be obtained by increasing the discharge resistance. If it is decided that say 1.75 seconds is a desirable maximum rate of field decay, the control equipment can be arranged to operate on curve 1 at approximately 150 volts armature and above and on curve 2 below 150 volts.

After having determined the generator characteristics the motor characteristics are checked to see that they fit into the cycle established by the generator. This is accomplished in somewhat the same manner as the calculation of the generator except that the field is rising due to application of full field for the stop and except that an additional factor, the inertia

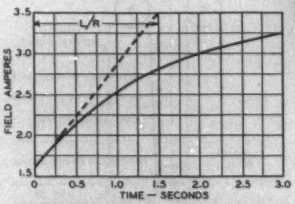


Figure 10. Typical field build-up characteristics for 125-horsepower motor

Figure 11. The main d-c panels for all processing operations are housed in these cubicles. The machinery is on the floor directly above

of the system,* must be taken into account. In this instance the resistance is the resistance in the motor field circuit. For practical purposes each motor may be treated independently and when so treated curves of which figure 10 is typical will result.

If the rate of motor field build-up does not differ appreciably from the rate of field decay previously calculated for the

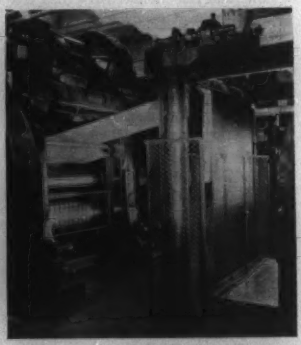


Figure 12. Material passing from calender number 1 into calender number 2 through the speed regulating gate. The dark surface of the material shows the rubber added by calender number 1

generator or in other words, if the motor becomes a generator, at approximately the same rate that the generator becomes a motor, a stable braking system may be expected. In general, if the motor does not operate over a speed range by field control greater than approximately two to one the motor will likely have inherently the desired field characteristics. For a greater speed range it may be found desirable to control the rate of motor field build-up.

Wind-Up Equipment

The essential differences between the wind-up operations and the operations

* Ascertain if the horsepower necessary to stop within the required time is within the capacity of the motor. This should be calculated at maximum speed which is the worst condition.

$$\text{Torque} = \frac{WR^2N}{307\,t} \text{ and horsepower} = \frac{N \text{ Torque}}{5{,}250}$$

in which WR^2 is the inertia of the system, N is the operating speed, and t the required seconds to stop.

Figure 13. Material from calender number 2 passing through the cooler and compensator. The material at the right is going to the wind-up. The rheostat mounted on top of the compensator controls the wind-up speed

previously described are first, that the wind-up cycle is intermittent due to the necessity of shutting down the wind-up to remove a full mandrel and insert an empty one and second, that the required operating speed range is appreciably increased because the difference in driving speed between an empty and full mandrel is added to the speed range of the continuous-production part of the system.

The matter of intermittent operation is provided for by inserting a material storage or compensator ahead of the wind-up. The compensator is shown in figure 2 from which it will be seen that if the wind-up has a production speed higher than that of the preceding part of the drive to the extent that the average production speed of the wind-up is equal to the continuous production speed of the preceding part, there will be eventually as much material taken out of the compensator as is put into it.

Intermittent operation and increased speed range of the wind-up are taken care of most effectively by again resorting to the adjustable-voltage system operating in conjunction with adjustable-speed motors. The wind-up motor is driven by an independent generator. The wind-up operator has at hand an interlocked-independent control station. In the interlocked position the wind-up starts and stops simultaneously with the preceding main drives. In the independent position, independent control of the wind-up is secured from a stop-thread-run control station.

Referring again to figure 2, it will be seen that if this control station is moved from stop to thread, full field is applied to the motor and field is applied to the generator through a generator-field threading resistor to give the armature voltage required for the desired threading speed.

Turning the control further or to the run position, transfers control from the threading resistor to the compensator-controlled rheostat. This rheostat is a combined generator and motor field rheostat designed to operate in the same manner as the combined rheostats for the calender motors. The setting of the rheostat is determined by the position of the compensator rolls from which it is operated in the same manner as the gate speed-regulating rheostats. From full to approximately half full compensator, the wind-up operates at full speed. From half full compensator to empty compensator, the speed is reduced from maximum to minimum. Limit switches are placed at the extreme compensator travels to shut down the drives should the normal operating range be exceeded.

All starts are made automatically through the threading resistor so that all slack in the equipment is taken up before the drive is thrown over to operating speed. As with the remainder of the drive, all stops for the wind-up are regenerative braking stops.

The Permatron—A Magnetically Controlled Industrial Tube

By W. P. OVERBECK
ASSOCIATE AIEE

THE Permatron is a new gas-filled control tube in which the initiation of a discharge may be controlled by an externally applied magnetic field. The possibility of this type of control has been recognized during the past few years,[1] but little attention has been paid to proper design or to the interesting applications of tubes built specifically for magnetic control. The present paper has been written as the result of research work which has shown that magnetic-control tubes are a reliable and useful addition to the field of electronics. The trademark "Permatron" has been chosen to indicate the use of magnetic control.

Construction and Operation

Figure 1 shows a typical Permatron construction. In addition to the anode and cathode, which are conventional, the bulb contains a cylindrical collector electrode which surrounds the discharge path. The controlling magnetic field is applied as shown through the poles of an electromagnet located outside the bulb. Nonmagnetic materials are used for all parts of the tube which might affect the proper distribution of the magnetic field. The most practical materials are graphite, for machined parts, and 18.8 stainless steel, which has a permeability of 1.1 when properly annealed. The nickel-alloy materials used for cathodes are operated at temperatures sufficiently high to reduce their permeability.

When a positive anode voltage and a magnetic field are applied to the Permatron, electrons emitted by the cathode are deflected and strike the collector. Due to the presence of the collector, which is usually maintained at a potential close to or equal to that of the cathode, this deflection takes place in a region of weak electrostatic field intensity and the electrons are removed from the discharge path before acquiring sufficient velocity to cause ionization. If the magnetic field is removed, the electrons proceed

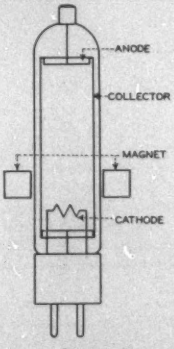


Figure 1. RM-201 Permatron

toward the anode, gaining velocity and producing ionization. Conduction continues at a low-voltage drop between anode and cathode until the anode voltage is removed or reversed. Thus, the initiation of a heavy current discharge may be controlled by diverting electrons which represent but a microscopic portion of the same current. For each value of anode voltage, there is a critical value of magnetic field intensity above which the discharge will not start. A theory of the relationship of this critical magnetic force to anode voltage and to the pressure of the gas within the tube has been developed and shows an interesting agreement with actual results.

An electron in an electrostatic field and a transverse magnetic field moves in a series of cycloid paths as shown in figure 2, and in a general direction at right angles to both fields. The values of magnetic and electrostatic fields normally employed in the Permatron are such that the dimensions of the individual cycloids are small and the electrons may be considered as moving sidewise in a straight line. However, due to the presence of gas molecules, the sidewise motion is broken up by collisions between electrons and molecules. At each collision, the electron may gain a little in progress in the direction of the electrostatic field. If we take, as an index of the effective sidewise motion of the electron, the number of cycloid paths in a mean free path, or average distance which an electron may travel without collision, and assume that this number must be a constant to prevent conduction in a given Permatron design, we obtain the following relation:

$$\text{magnetomotive force} = K\sqrt{EP}$$

giving the critical magnetomotive force as a function of anode voltage E, and gas pressure P. K is a constant which includes proportionality factors between pressure and mean free path, magnetomotive force and magnetic field intensity, anode voltage and electrostatic field intensity, and the assumed constant ratio between mean free path and length of the cycloid paths. Figure 3 shows values of the constant K (magnetomotive force/$\sqrt{EP}$) plotted against magnetomotive force for the full range of control of a mercury-vapor Permatron. The deviation from the theoretical constant value at low values of magnetomotive force corresponds to conditions under which the dimensions of the individual cycloid paths become comparable in size to the internal dimensions of the tube.

When a straight cylindrical collector such as that of figure 1 is used, the mag-

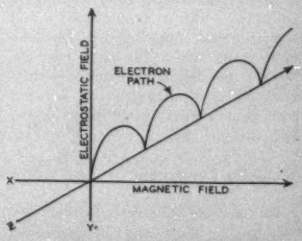


Figure 2. Path of an electron in electrostatic and transverse magnetic fields

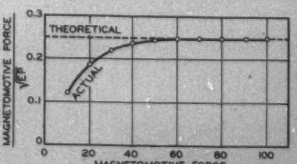


Figure 3. Comparison of Permatron theory with actual test data

Paper number 39-20, recommended by the AIEE subcommittee on electronics, and presented at the AIEE winter convention, New York, N. Y., January 23-27, 1939. Manuscript submitted November 3, 1938; made available for preprinting December 10, 1938.

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Development of the Permatron and its methods of application is the result of co-operation of the members of the research and development department of the Raytheon Production Corporation.

1. For all numbered references, see list at end of paper.

netic sensitivity of the Permatron increases approximately as the cube of the ratio of distance between anode and cathode to diameter of the collector. This is due partly to the resulting decrease in electrostatic field intensity in the control region and partly to the fact that a greater length of collector surface is available to catch electrons. The practical limits of sensitivity are reached when the shielding effect of the collector becomes so great as to prevent starting of the tube at reasonably low anode voltages when no magnetic field is present.

When other requirements such as the proper distribution of heat in a mercury-vapor tube must be met, a construction such as that of figure 4 is convenient. Here, the effective region of the collector is a cylindrical constriction formed by holes in a pair of graphite disks. The magnetic field is led into this region through iron armatures from a part of the bulb where location of the external magnet is most convenient. The use of two graphite disks, one above and the other below the iron poles, helps to shield the iron, which might otherwise tend to produce secondary electrons, and increases the length of the effective region. The outer cathode heat shields of this tube are made of nonmagnetic steel.

Characteristics

There are three distinctly different types of operation obtainable with the Permatron. Characteristics are shown in figure 5 for simple magnetic control in which the collector is directly connected to the cathode. These curves indicate the variation in control characteristics caused by changes in condensed-mercury temperature in the tube of figure 4. For circuit design purposes, it is most convenient to express the magnetic field intensity in terms of ampere turns applied to an electromagnet located in the most effective position. To give an approximation of the power needed for control, the value of 300 ampere turns in figure 5 represents 2.34 watts consumed in the magnet used for obtaining data for the curves. The tube of figure 1 requires about 0.075 watts for control of its maximum allowable anode voltage. These control power requirements are small in comparison to the power which the tubes will handle. The tube shown in figure 4 will control 16 kw while that of figure 1 will control 10 watts.

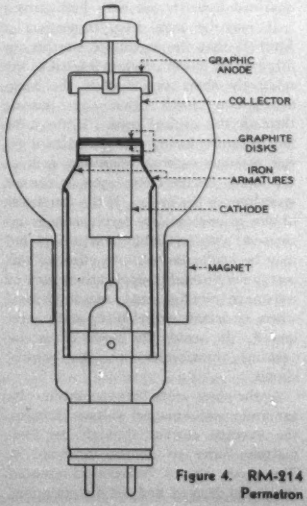


Figure 4. RM-214 Permatron

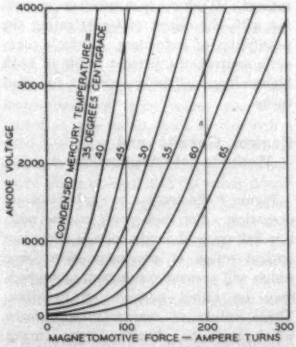


Figure 5. Characteristics of RM-214 Permatron

A second type of operation is that in which varying collector potentials are employed. This is similar to grid control except for the fact that the controlling effects of collector potential and magnetic field are interrelated as shown by the curves of figure 6. These particular curves indicate that the negative collector potentials and magnetic field intensity have an additive effect. This is not always true because it has been found that, in some other tube constructions, the minimum anode firing voltage may occur at a negative collector potential or at some value of magnetomotive force greater than zero. Such unusual effects are possible because the region where the magnetic field is applied may be located in a position where collector potential has a great effect on electrostatic field intensity or in a position where the electrostatic field intensity does not vary appreciably with collector potential. Also, the magnetic and electrostatic fields may be used to produce focusing effects which counteract one another.

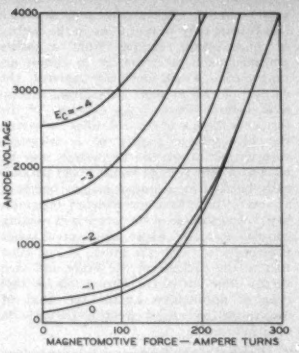


Figure 6. RM-214 Permatron characteristics showing effect of varying collector potential

Condensed mercury temperature = 45 degrees centigrade

The third type of operation is that in which ionization may be present in the tube without producing a discharge between anode and cathode. A Permatron such as that of figure 4 may be operated with a discharge between collector and cathode; in which case, the magnetic field may be used to prevent the discharge from spreading through the holes in the graphite disks to the anode. When the cathode-collector discharge is small, of the order of one milliampere, this has the same effect as would be obtained by moving the cathode closer to the holes in the graphite disks and produces anode control characteristics similar to those of figure 5, except that greater values of magnetomotive force are required and the anode firing voltage at zero magnetomotive force is greatly reduced. This type of operation has been used to make a tube designed for high-voltage applications more useful in circuits where low anode voltages are employed.

Field of Application

The Permatron performs the same type of service as has been obtained from thyratrons[2] and ignitrons.[3,4] Thus, its field of application overlaps to some extent. In the same field, it has three features which are useful in certain types of applications:

1. An electromagnetic control may remain insulated from the tube and its associated

power circuit. The applications in which this feature may be useful are in the control of high-voltage circuits from a safely grounded control circuit or in circuit arrangements which normally prevent the control of two or more tubes from a common control source. An example of the former is the use of control tubes for keying the high-voltage supply of a telegraph transmitter[4] where the Permatron may be used as a high-voltage rectifier and periodically blocked by a control magnet operated at low voltage from an ordinary telegraph key. An example of the latter is in welding control circuits[5,7] where the control tubes are connected with the anode of one tube tied to the cathode of the other and vice versa. The use of the Permatron for this type of application avoids the need of connecting the control circuit to the cathode of either tube.

2. Control of the Permatron is independent of the polarity of the magnetic field. In cases such as the welding circuit mentioned above or in full-wave rectifier circuits where the anode voltages of two tubes are 180 degrees out of phase, the voltages applied to their control magnets may have the same polarity or a single magnet may be used to control both tubes.

3. The Permatron produces unusual phase-shift control characteristics which are described in detail later.

The usefulness of the Permatron extends to a new field of applications due to other factors which are listed below:

1. New combinations with moving machinery are possible because the Permatron may be controlled by moving permanent magnets. An example of this is in the problem of elevator leveling or control where permanent magnets might be mounted on the cage to operate Permatrons at various levels in the shaft.

2. A wider application to communication circuits or measuring instruments is possible because of the lack of reaction between the tube and control magnet. The control impedance remains the same and is linear whether the tube is conducting or not. Thus, the Permatron may be operated directly from a transmission line without danger of reflection or may be operated from carefully balanced measuring circuits without danger to instruments.

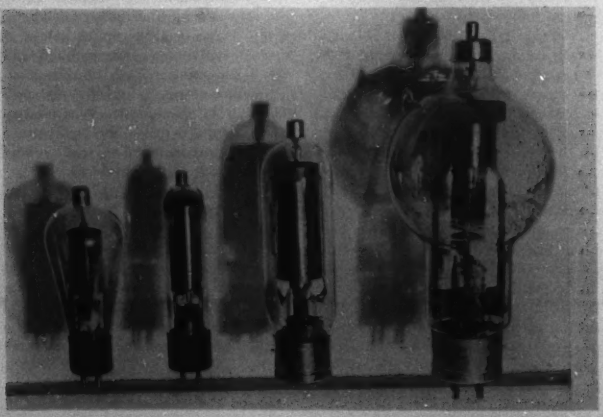
3. Operation of the control from extremely low voltages is possible, although heavy control currents are required. As an example, the tube illustrated in figure 1 can be controlled by a voltage lower than six microvolts when a single-turn control magnet is used.

Most of the development of Permatrons has been confined to the small tubes and medium power industrial tubes illustrated in figure 7. The ratings of the tubes range from an average current of 0.1 to 8 amperes and up to 3,500 volts. There is, however, no factor which prevents application of the same principles to tubes of higher voltage and current ratings. Work on such tubes is proceeding with the object of investigating the possibility of extending, through magnetic control, the present limits of both high-voltage and heavy-current gas-filled tubes.

Control Circuits and Methods of Application

Figure 8 illustrates the analysis of a-c operation. For each point on the positive half cycle of anode voltage, there is a critical value of magnetomotive force which will prevent conduction and which may be either positive or negative. These values of magnetomotive force which may be obtained from curves similar to those in figure 5, form a closed oval as shown by the dotted line. If an alternating magnetomotive force is applied to the control magnet, conduction starts in each cycle at the point where the magnetomotive force wave intercepts the critical oval and continues until the anode voltage becomes negative. This period of conduction, indicated by the shaded portion of the diagram, may be increased or decreased by varying the phase relation between anode voltage and magnetomotive force.

Figure 7. Experimental Permatrons



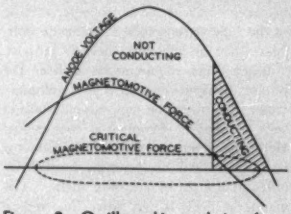


Figure 8. Oscillographic analysis of a-c operation

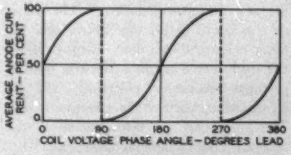


Figure 9. Output characteristic of Permatron with phase-shift control

Phase shift control of this type has been described in connection with other types of control tubes[2] so it is possible to limit the present discussion to unusual results obtained from its use with Permatrons.

It may be seen, from inspection of figure 8, that the instant of starting, or firing angle, in each cycle is limited to the relatively short period that the magnetomotive force wave is passing through the critical oval. If the tube fails to start during this period as a result of some external condition such as the anode circuit being open, it cannot start later in the cycle. If the amplitude of the magnetomotive force wave is increased, this available starting period may be made shorter. An effect of this sort is very useful in applications such as resistance welding and motor control where an accurately set firing angle is required. It avoids the need of special peaking transformers in the control circuit.

As the phase angle between anode voltage and control-magnet voltage changes, the average current through the Permatron varies as shown in figure 9. The anode current variation is repeated every 180 degrees, and the discontinuous

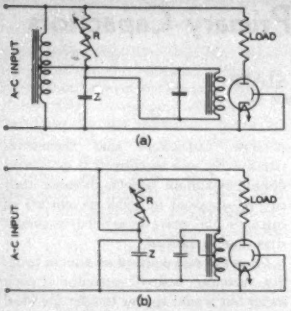


Figure 10. Permatron phase-shifting circuits

points occur at the power-factor angle of the control magnet which is usually close to 90 degrees. In welding or in full-wave rectifier circuits where tubes are connected with their anode voltages 180 degrees out of phase, the two control-magnet voltages may be in phase or a single magnet may be used to control both tubes.

Two circuits which may be used for phase-shift control of the Permatron are shown in figure 10. The first (*a*) is an adaptation of the conventional type of phase-shift circuit. The reactive element *Z* may be either a capacitor or an inductor. When the resistor *R* is varied from zero to infinity, the phase angle of the control magnet varies from zero to 180 degrees with respect to the anode voltage. A capacitor whose capacitance resonates with the control-magnet inductance at the power-line frequency may be connected in parallel with the control magnet to reduce the current drawn from the phase-shift circuit. The second circuit (*b*) avoids the need of a center-tapped control-voltage source by using a center-tap on the control magnet. This circuit is easy to understand when it is realized that it is the same as the one above except that the connections are reversed. The magnet takes the place of the center-tapped source and the terminals which would normally be the output of the phase-shift circuit are connected to the power lines. The impedance *Z* and the mean value of the resistor *R* should be large compared to the impedance between the center-tap of the control magnet and the two outer terminals when the latter are short-circuited and should be small compared to open-circuit impedance between the outer ends of the control magnet. Use of a resonating capacitor across the magnet makes the latter value larger.

In automatic control circuits, it is usually preferable to obtain phase-shift control from direct current. This preference is due to the fact that such control devices often include a vacuum-tube amplifier which produces a varying d-c output. A very useful circuit for this type of control is shown in figure 11. Two coils are wound on each control magnet, one to be operated from alternating current and the other from direct current. When two tubes are used, these coils may be arranged so that the alternating voltages induced in the two d-c coils are balanced out. The same result may be accomplished with single-coil magnets if the coils are connected in a balanced bridge circuit with the alternating current applied to one pair of opposite corners and the direct current to the other corners. The oscillographic drawing below the circuit diagram shows the results obtained. Due to the balancing connection, the d-c magnetomotive force shifts the two a-c magnetomotive force waves in opposite directions. These magnetomotive force waves are illustrated as sine waves, each drawn with a solid line during the half cycle that its associated anode is positive. Since one wave shifts upward and the other downward, the firing angles of the two tubes shift in the same direction and their output currents remain balanced. If the connections to the a-c coils are reversed, the direction of shift in firing angle with a given change in d-c magnetomotive force is reversed.

A smooth control of output current of a Permatron may be obtained with moving permanent magnets by applying the same principle as the circuit of figure 11.

Although several complete circuits using Permatrons have been developed, a detailed description of all of them would require more space than could be alloted to one paper. However, the full wave rectifier circuit of figure 12 is shown in order to give an example of the combination of a few of the principles described above in a complete circuit. The control magnet system is a combination of figure 11 and figure 10 (*b*). The d-c coils are operated by an amplifier tube whose plate current is controlled by variations in output voltage of the rectifier. The phase-shift circuit of the a-c coils is adjusted to give the maximum rate of change of output voltage for a given change of current in the d-c coils and to set the mean output voltage at a value which produces the optimum performance of the amplifier tube. A resistance and capacitor time-delay circuit is used in the grid circuit of the amplifier to prevent hunting. This particular circuit is designed to give a constant output voltage regardless of input voltage or load variations. If the d-c coils are of low impedance and connected in series with the load, the rectifier may be made to have a drooping characteristic or a rising characteristic depending on the phasing of the a-c coils.

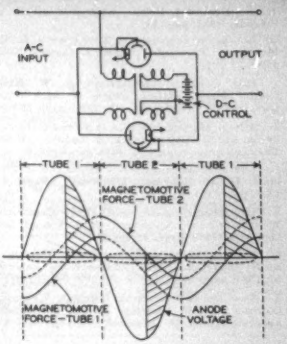


Figure 11. Circuit diagram and analysis of combined a-c and d-c magnetic control

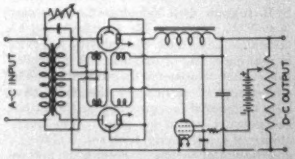


Figure 12. Fundamental circuit diagram of Permatron-controlled rectifier

Conclusion

Magnetic control as described above has proved itself both reliable and efficient and, having so many useful features, it should find many industrial applications. Moreover, since it is possible to obtain both grid control and magnetic control effects in the same tube, there are many applications in which the desirable qualities of both types of control may be obtained simultaneously. In circuit combinations and in possible variations of control characteristics, the Permatron should provide a fertile field for new ideas.

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(*b*) U. S. Patent No. 2,124,682—P. L. Spencer.
(*c*) Control of Gaseous Conduction, V. Bush and C. G. Smith. AIEE Transactions, volume 41, 1922, page 402.
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2. HOT CATHODE THYRATRONS, A. W. Hull. *General Electric Review*, volume 32, April 1929, pages 213–23; volume 32, July 1929, pages 390–9.

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5. THE PERMATRON—A NEW TYPE OF RECTIFIER WITH MAGNETIC CONTROL, *QST*, volume 22, September 1938, pages 42 and 86.

6. A NEW TIMER FOR RESISTANCE WELDING, R. N. Stoddard. AIEE TRANSACTIONS, volume 53, 1934, pages 1366–70.

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Discussion

S. B. Ingram (Bell Telephone Laboratories, New York, N. Y.): Mr. Overbeck and his associates have done the industry a service in making a line of magnetically controlled gas tubes commercially available. The advantages of devices of this type have been recognized for some time as the author has pointed out in his paper. The availability of a new device, however, is always a great stimulus to its wide application and we shall now have an opportunity to see the magnetically controlled tube prove its mettle in competition with other types of gas-filled control tubes.

There is one characteristic of mercury-vapor-filled Permatrons which, I believe, will be a considerable impediment to its circuit application. This is the variability of its characteristics with condensed mercury temperature. The characteristics of the thyratron or grid-controlled gas-filled tube also vary with temperature, but extreme shifts in the characteristic take place only below condensed-mercury temperatures of about 40 degrees centigrade. In the ordinary operating temperature range from 40 degrees centigrade to 80 degrees centigrade the characteristics are relatively independent of temperature. In the Permatron, the variability extends over the whole temperature range as Mr. Overbeck's figure 5 shows and as, in fact, his theory of breakdown demands. Rare-gas-filled tubes would be free from this disadvantage although their use would necessarily be confined to low-voltage circuits. I should like to ask if any work has been done on Permatrons with rare-gas filling.

W. P. Overbeck: Mr. Ingram's discussion is greatly appreciated. As pointed out in the paper, our work has led to the discovery of previously unrecognized advantages of magnetic control and it is natural to expect that, with special tubes available, other engineers will be able to add important contributions. In addition to the competitive situation mentioned by Mr. Ingram, it is to be hoped that the unusual features of the Permatron will create a new field of application.

In contradiction to the theory of control which I have proposed, I believe that there is a possibility of reducing variations of characteristics with temperature. Non-varying characteristics of the thyratron in the range of temperatures mentioned by Mr. Ingram are not true of all types. For example, the *FG*-43 and *KU*-628 show considerable variation in this range. We are thus led to the conclusion that refinements of design are responsible for the improved characteristics of types such as the *FG*-29. A similar refinement in design of the Permatron would be such that tube construction, rather than vapor pressure, would determine the effectiveness of magnetic deflection. On the other hand, it should be noted that in an experimental industrial installation, mercury-vapor Permatrons have operated over 5,000 hours without difficulty from characteristic variations. This is, of course, due to proper circuit design.

Considerable work has been done on Permatrons with rare-gas filling. The two tubes shown in the center of figure 7 are made with argon gas. This removes variation of characteristics with ambient temperature.

Secondary Versus Primary Capacitors

By F. M. STARR
MEMBER AIEE

Synopsis: Secondary capacitors cost more than primary capacitors but they offer some additional benefits which may offset the additional costs. There are presented herein the results of a comprehensive economic study covering a wide variety of circuit and load conditions on both network and radial distribution systems to establish within reasonable limits the probable field of application of the secondary capacitor.

From the results of the study it appears that secondary capacitors can be justified in practically all cases on secondary networks but have a limited application on primary radial distribution systems.

DURING the past two years shunt capacitors have been applied to distribution systems in increasing quantities. Continual increases in reactive loads due to refrigerators, air conditioning, fans, and other small motor loads have had their destructive effects and corrective measures have more than ever become necessary.

Reactive amperes originate at the load and they carry their destructive effect in the form of excessive voltage drops, thermal overloads, and energy losses, back to the generator. Naturally enough, corrective measures to affect the maximum benefits should be located as close to the load or source of reactive as possible. Capacitors lend themselves particularly well as corrective devices to obtain maximum benefits because they can be obtained in small increments of capacity and may be applied in proper sizes close to the load.

From the viewpoint of maximum benefits, therefore, a small capacitor at each meter box would appear to offer the ideal correction. On the other hand, from the viewpoint of maximum benefits commensurate with maximum economy, the relative costs of capacitor correction applied at various points in the distribution system must be factored.

The cost of capacitors varies principally with the size of the individual unit and with the voltage rating of the unit. At the present stage of the art, design and manufacturing limitations are such that the capacitor having the lowest cost per kilovolt-ampere is a 10- or 15-kva unit having a voltage rating of 2,300 or 4,000 volts. This, of course, means that the lowest cost correction is that which can be applied to the primary feeder. The difference in cost between primary and secondary capacitors is quite substantial (see figure 3) and it probably is for this reason that practically all capacitors which have been applied by utilities for reactive correction have been primary-feeder capacitors.*

Although secondary capacitors cost more, they do offer some additional advantages over primary capacitors. Consider for a moment what these additional advantages consist of:

Comparative Benefits of Secondary Versus Primary Capacitors

The elimination of reactive kilovolt-amperes from a system releases system

Paper number 39-62, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE winter convention, New York, N. Y., January 23–27, 1939. Manuscript submitted September 28, 1939; made available for preprinting December 30, 1938.

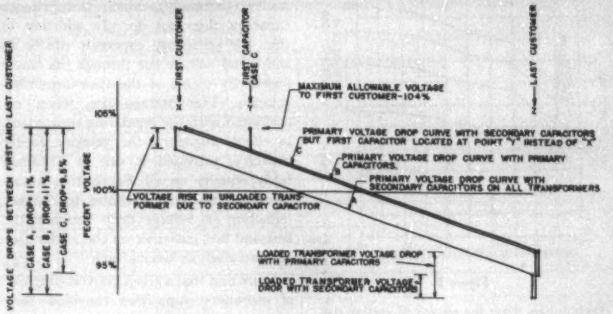
F. M. STARR is a member of the central station engineering staff of the General Electric Company, Schenectady, N. Y.

The author wishes to acknowledge here the large amount of work by T. F. Skinner in making all of the calculations and preparing all of the curves used in this paper and also the contribution of O. B. Falls in preparation of the manuscript.

* Capacitors applied by industrials, of course, are necessarily low-voltage capacitors since the utilization voltage is in most cases the only voltage available in an industrial plant.

Figure 1 (right)

These curves show that secondary capacitors do not give any additional reduction in voltage drop between first and last customer if all transformers are equipped with the secondary units. To gain additional reduction in voltage drop, the secondary capacitor installations should be confined to the section of line between *Y* and *Z* above. Point *Y* is that point at which the primary feeder line drop is equal to the voltage rise in an unloaded transformer due to a secondary capacitor. In the above curves, it is assumed that the first transformer may be unloaded at peak feeder load


FIRST CUSTOMER
FIRST CAPACITOR CASE C
LAST CUSTOMER
MAXIMUM ALLOWABLE VOLTAGE TO FIRST CUSTOMER-104%
PRIMARY VOLTAGE DROP CURVE WITH SECONDARY CAPACITORS BUT FIRST CAPACITOR LOCATED AT POINT "Y" INSTEAD OF "X"
PRIMARY VOLTAGE DROP CURVE WITH PRIMARY CAPACITORS.
PRIMARY VOLTAGE DROP CURVE WITH SECONDARY CAPACITORS ON ALL TRANSFORMERS
VOLTAGE RISE IN UNLOADED TRANSFORMER DUE TO SECONDARY CAPACITOR
LOADED TRANSFORMER VOLTAGE DROP WITH PRIMARY CAPACITORS
LOADED TRANSFORMER VOLTAGE DROP WITH SECONDARY CAPACITORS
VOLTAGE DROPS BETWEEN FIRST AND LAST CUSTOMER
CASE A, DROP=11%
CASE B, DROP=11%
CASE C, DROP=8.8%
PERCENT VOLTAGE
105%
100%
95%

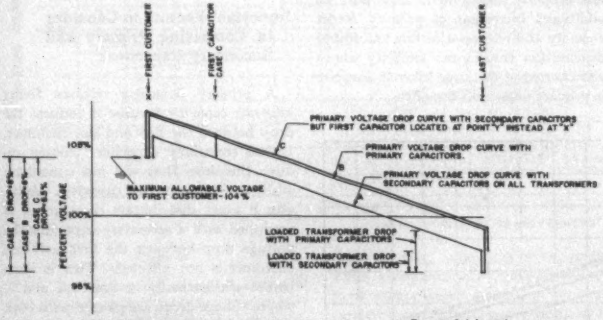

FIRST CUSTOMER
FIRST CAPACITOR CASE C
LAST CUSTOMER
PRIMARY VOLTAGE DROP CURVE WITH SECONDARY CAPACITORS BUT FIRST CAPACITOR LOCATED AT POINT "Y" INSTEAD AT "X"
PRIMARY VOLTAGE DROP CURVE WITH PRIMARY CAPACITORS.
PRIMARY VOLTAGE DROP CURVE WITH SECONDARY CAPACITORS ON ALL TRANSFORMERS
MAXIMUM ALLOWABLE VOLTAGE TO FIRST CUSTOMER-104%
LOADED TRANSFORMER DROP WITH PRIMARY CAPACITORS
LOADED TRANSFORMER DROP WITH SECONDARY CAPACITORS
CASE A DROP=8%
CASE B DROP=8%
CASE C DROP=6.5%
PERCENT VOLTAGE
108%
100%
98%

Figure 2 (above)

A similar comparison is made in the above curves as in figure 1 except that it is assumed here that all transformers will be loaded at peak feeder load. In this case, however, it is still true that secondary capacitors do not give additional reduction in voltage drop over primary capacitors unless they are confined to that section of the feeder between points *Y* and *Z*. For either of the conditions assumed in figures 1 or 2 it is necessary properly to set the line-drop compensator to obtain the indicated results

capacity in one or both of two ways. Correction of reactive kilovolt-amperes reduces voltage drop and it also reduces net kilovolt-amperes, so depending on whether voltage drop or thermal capacity is the limiting factor, the value of released system capacity will be calculated in one of two ways.

The kilowatt carrying capacity of overhead primary feeders is practically always limited by voltage drop in the feeder so the advantage of the capacitor in releasing feeder capacity is measured as a direct function of the degree of re-

Figure 3 (below)

These curves show the relative costs of primary and secondary capacitors. The cost per kilovolt-ampere of primary capacitors is about constant since they are always multiples of 10- or 15-kva units. In this study primary 4-kv capacitors had a fixed installed cost of $7.55 per kilovolt-ampere and 13.8-kv capacitors had a fixed installed cost of $12.60 per kilovolt-ampere. The installed cost of secondary capacitors varies considerably as noted above. On secondary networks, however, the cost was fixed at $22.40 per kilovolt-ampere since these were all multiples of 5-kva units

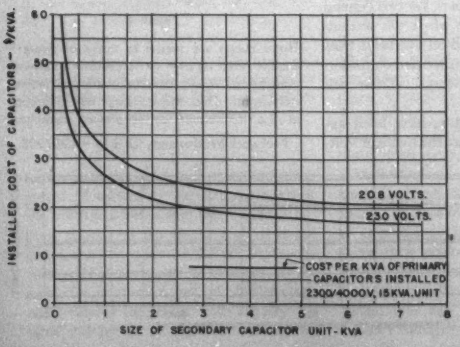
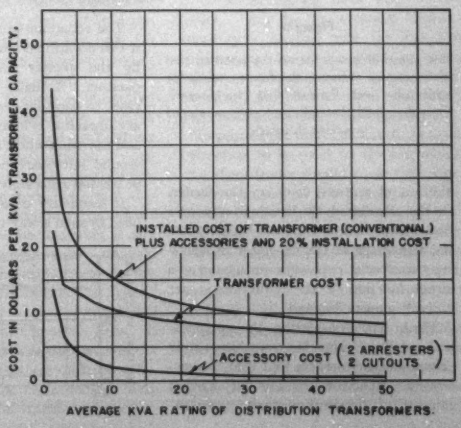


Figure 4

The curves below summarize the unit distribution transformer costs for the conventional type of transformer on overhead lines using two lightning arresters and two fuse cutouts, as used in this study



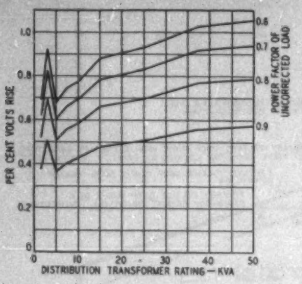


Figure 5

These curves show the amount of voltage rise which secondary capacitors produce in the distribution transformers on overhead lines. It is assumed here that the feeder power factor is corrected to unity and that the ratio of total transformer kilovolt-amperes to feeder kilovolt-ampere demand is two

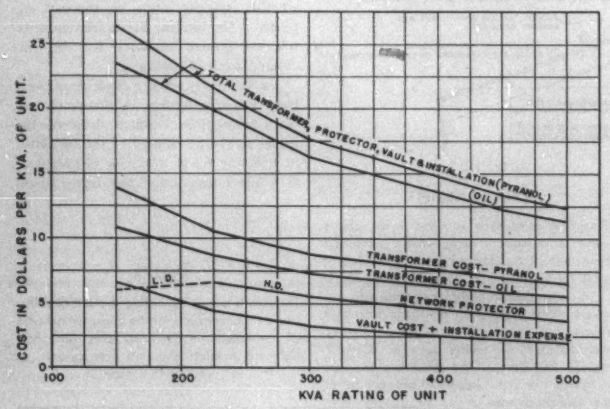


Figure 6

This group of curves shows the installed cost of secondary network transformer vaults for both oil- and Pyranol-filled transformers. Only the oil-filled transformer costs were used in making this study

duction of voltage drop on the feeder. On the other hand, the limiting factor on a transformer is its thermal capacity, so the advantage of the capacitor in releasing transformer capacity is measured as a direct function of the reduction in net kilovolt-ampere demand.

Thus, now considering the comparative merits of secondary capacitors over primary capacitors, we find that the secondary capacitor releases a certain amount of distribution transformer capacity (thermally), which the primary capacitor does not do. In addition to this, the secondary capacitor effects an additional voltage rise through the transformer by virtue of the transformer reactance. This voltage rise, when coordinated with the regulating equipment, in effect, augments the primary feeder capacity, provided it can be obtained fairly equally on all distribution transformers, since it contributes to the net reduction in voltage drop between the first and last customer on the feeder (see detailed analysis hereinafter).

So we find that a given kilovolt-amperes of secondary capacitors provided they are properly distributed, may add an additional increment of primary feeder capacity and releases a certain amount of distribution transformer capacity above and over what the same kilovolt-amperes in primary capacitors can offer.

The economic problem is to determine if this additional benefit is or is not offset by the greater cost of secondary capacitors. Actually, there are two general cases to consider—one where the secondary capacitor is located on overhead lines and the other where it is located on underground secondary networks. These will be treated separately.

If secondary capacitors have been applied in such a way that the average voltage level is higher than could be obtained with primary capacitors there will probably result an increase in revenue which may properly be considered an additional benefit. Although most engineers agree that there will be some increase in revenue with a higher voltage level, there is some difference in opinion as to the amount of increase. In the economic comparison of this study the additional revenue has been evaluated by a method acceptable to most engineers and the results have been prepared alternatively considering the additional revenue as a benefit and ignoring it. The details are given in the appendix.

Important Factors to Consider in Comparing Primary and Secondary Capacitors

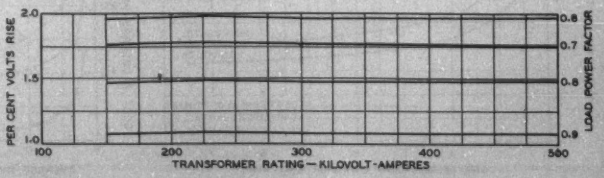
A primary capacitor releases feeder kilowatt capacity because it reduces the drop between the first and last customer. Unless secondary capacitors further reduce this drop they will not contribute additional kilowatt line capacity. Actually if every distribution transformer is equipped with a secondary capacitor the voltage drop between the first and last customer is not affected. This is illustrated schematically in figures 1 and 2, where voltage drops are plotted with both primary and secondary capacitors and considering alternatively that the first transformer may or may not be loaded at peak feeder load. It is assumed (arbitrarily) in these diagrams that each distribution transformer has $2^1/_2$ per cent voltage drop when fully loaded and $1^1/_2$ per cent rise when equipped with secondary capacitors.

On most feeders the allowable voltage to the first customer (in this case assumed to be 104 per cent) determines the amount of boost permitted the feeder regulators at peak load. If a voltage rise of 1.5 per

Figure 7

These curves are similar to those of figure 5 except they apply to secondary network transformers rather than to overhead-line installations. They show voltage rise produced in the transformer by secondary capacitors

Network transformers, 13.8 kv—120/208



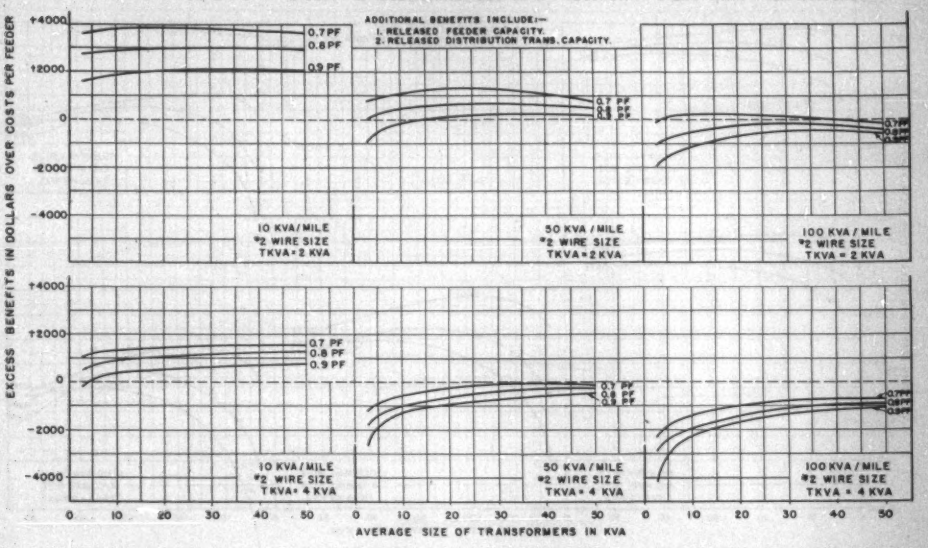


Figure 8

Here are plotted the values of additional benefits over costs of secondary over primary capacitors for overhead lines of a rather low load density—that is, 10, 15, and 100 kva per mile. The dollar values are total capitalized benefits in excess of or less than additional costs of secondary over primary capacitors per feeder. In all cases, any specific set of data plotted here applies to a feeder having such a length and loading as to give exactly 10 per cent voltage drop at peak load

The additional benefits tabulated here include:

1. Released feeder capacity
2. Released distribution transformer capacity

The ratio of transformer kilovolt-amperes to feeder kilovolt-ampere diversified demand was assumed alternatively two and four. The power factors assumed were 0.7, 0.8, and 0.9. The average size of distribution transformers ranged from 5 to 50 kva

It may be noted that for the conditions considered here the secondary capacitors cannot be justified except at the light load densities and low power factors

cent is introduced in each transformer by means of secondary capacitors, in effect the voltage level of the whole feeder has been raised 1.5 per cent; and to avoid giving the first customer 1.5 per cent overvoltage it is necessary to readjust to the regulator to give 1.5 per cent less voltage which leaves the feeder with exactly the same voltage to all customers as before the secondary capacitors were applied. Thus equipping all transformers with their proportionate amount of secondary capacitor correction does not result in any increase in kilowatt feeder capacity over that which can be obtained with the same kilovolt-amperes in primary capacitors.

However, if the secondary capacitors are not applied proportionately to all transformers but only to those between points *Y* and *Z* in figures 1 and 2 (point *Y* is that point at which the feeder voltage drop at peak load is equal to the voltage rise produced in the transformer by the capacitor), there will result in effect a reduction in the voltage drop between the first and last customer, in this case 1.5 per cent, and a corresponding increase in kilowatt capacity of the feeder.

In figures 1 and 2 there is illustrated rather simply the comparative voltages on the primary feeder and transformer secondary for the conditions of *A*—primary capacitors uniformly distributed, *B*—secondary capacitors uniformly distributed, and *C*—secondary capacitors distributed only between points *Y* and *Z* of the feeder. In figure 1 it is assumed that the first transformer may be unloaded at peak feeder load, and in figure 2 it is assumed that all transformers will have their peaks at the same time. It may be noted that under the last assumption there is less voltage difference between first and last customer but with either assumption of transformer loading the secondary capacitors contribute exactly the same amount of improvement. Note also that the only voltage benefit obtained by applying secondary capacitors to all transformers, as indicated in curve *A*, would be a reduction in the necessary voltage range of the regulator.

Figures 1 and 2 demonstrate further that in applying secondary capacitors, careful consideration must be given to the loading of the transformers. If all transformers have their peak loads at about the same time, the results are different than if any particular transformer is unloaded during peak load on the feeder. Only by an accurate study of transformer loading can the line-drop compensator be set properly to obtain maximum benefits from the secondary capacitors and also to avoid overvoltage conditions on specific transformers.

In general the total amount of capacitor correction to be used on the secondaries of a given feeder should equal that which would be used on the primary. This is usually made equal to the average reactive kilovolt-amperes of the diversified feeder load. Any deviation from this rule, plus or minus, results in a partial sacrifice in the maximum reduction in feeder energy losses otherwise obtained.

If the capacitor correction is equal to the average feeder reactive kilovolt-amperes and a proportional amount of it is applied to the secondary of each transformer, because of diversity, the average

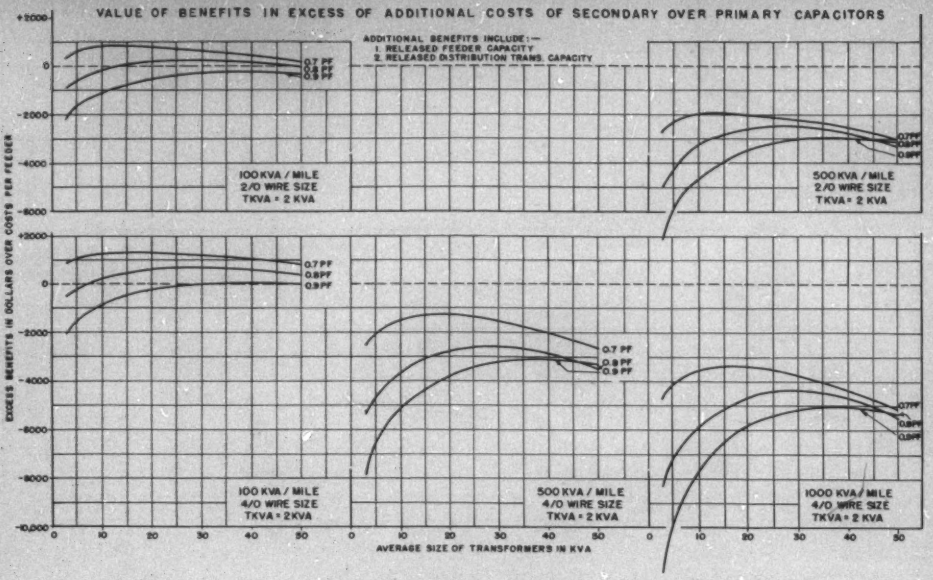


Figure 9

Here are plotted the values of additional benefits over cost of secondary over primary capacitors for overhead lines of somewhat higher load densities than those considered in figure 8. The load densities considered here were 100, 500, and 1,000 kva per mile. In keeping with these densities the conductor sizes assumed were 2/0 and 4/0. The dollar values are total capitalized benefits in excess of or less than additional costs of secondary over primary capacitors per feeder. In all cases any specific data plotted here applies to a feeder having such a length and loading as to give exactly 10 per cent voltage drop at peak load

Here again the additional benefits capitalized include (1) released feeder capacity, and (2) released distribution transformer capacity. The ratio of transformer kilovolt-amperes to diversified feeder demand was two. Here again the average size of distribution transformer was assumed to vary from 5 to 50 kva

Note that under these conditions secondary capacitors cannot be justified, even at the light load density of 100 kva per mile unless the power factor is fairly low

reactive load on any one transformer will only be partially corrected. Moreover, it is important to note that whereas the reactive kilovolt-amperes is reasonably constant on most feeders, this is not at all true of loads on specific transformers.

From the viewpoint of voltage control it is perhaps preferable to distribute the capacitor correction in direct proportion to transformer rating with the first installation located at a point on the feeder at which the peak-load voltage drop is equal in magnitude to the voltage rise produced in the transformer by the secondary capacitor. This procedure would insure uniform voltage rise in all transformers and also would insure the maximum additional feeder kilowatt capacity. On the other hand, with specific transformers having particularly bad power-factor or unusual load conditions, it may be desirable to concentrate more than a proportionate amount of capacitors.

It should be emphasized that unless considerable care and study is given to the application of secondary capacitors, particularly on radial secondaries, the calculated additional benefits will not be realized. In the case of banked secondaries or secondary networks the problem is not so acute, because load diversity is obtained in the network itself, which approaches that obtained in the primary feeder with radial distribution.

Scope of Economic Analysis

To obtain a broad picture of the economic merits of secondary capacitors, it was necessary to consider a great variety of radial overhead feeders as well as secondary networks. Actually 33 overhead lines were analyzed and 24 variations in circuit design and load conditions were:

Radial Overhead Feeders:	
Conductor sizes	numbers 2, 2/0, 4/0
Load density, kilovolt-amperes per mile	10, 50, 100, 500, 1,000
Power factor	0.7, 0.8, 0.9
Average transformer size	$1^1/_2$ kva to 50 kva
Ratio of transformer kilovolt - amperes to total kilovolt-ampere demand	2, 4

In each case the primary voltage was assumed to be 4,160 volts, since this is the voltage rating of the lowest-cost primary capacitor.

Network Systems:	
13.8-kv underground cable	4/0, 350,000 circular mils
Load density, kilovolt-amperes per mile	500, 1,000, 3,000, 5,000
Power factor	0.7, 0.8, 0.9
Average transformer size	150 kva to 500 kva
Ratio of transformer kilovolt-amperes to total kilovolt-ampere demand	1.5

The primary voltage was assumed to be 13.8 kv in each case.

In all cases the allowable primary voltage drop on 4.16-kv overhead lines

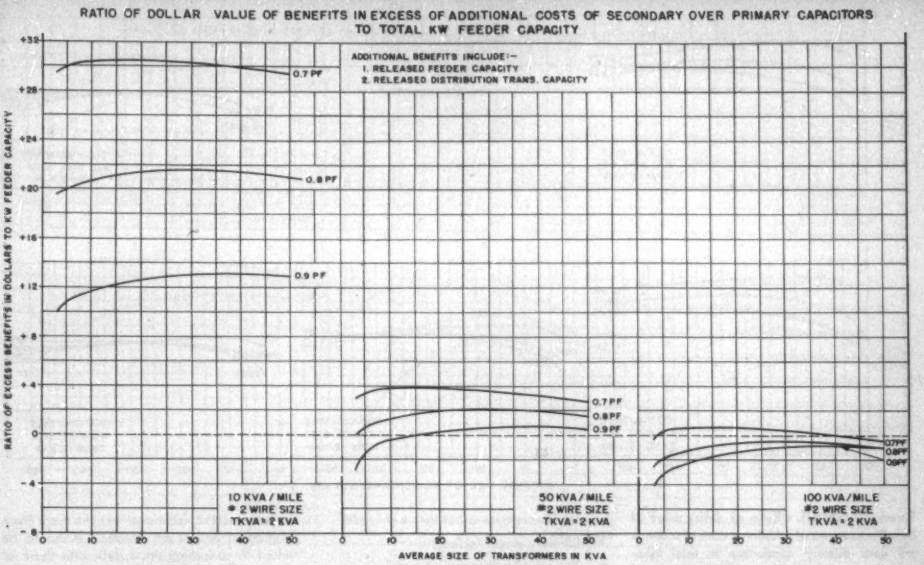

RATIO OF DOLLAR VALUE OF BENEFITS IN EXCESS OF ADDITIONAL COSTS OF SECONDARY OVER PRIMARY CAPACITORS TO TOTAL KW FEEDER CAPACITY
ADDITIONAL BENEFITS INCLUDE:—
1. RELEASED FEEDER CAPACITY
2. RELEASED DISTRIBUTION TRANS. CAPACITY
0.7 PF
0.8 PF
0.9 PF
10 KVA / MILE
#2 WIRE SIZE
TKVA = 2 KVA
50 KVA / MILE
#2 WIRE SIZE
TKVA = 2 KVA
100 KVA / MILE
#2 WIRE SIZE
TKVA = 2 KVA
RATIO OF EXCESS BENEFITS IN DOLLARS TO KW FEEDER CAPACITY
AVERAGE SIZE OF TRANSFORMERS IN KVA

Figure 10 (above)

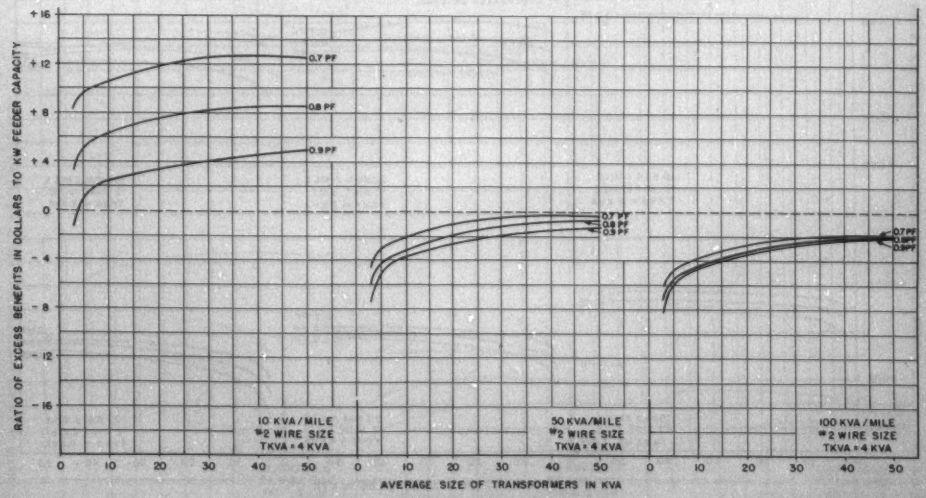
The data plotted in these curves cover similar conditions to that of figure 8 except that the additional benefits of secondary over primary capacitors have been plotted as a ratio of dollars benefit to kilowatt feeder capacity rather than dollar benefit per feeder. These data cover the set of conditions in the upper half of figure 8, that is, number 2 conductor size, load densities of 10, 50, and 100 kva per mile, and a ratio of transformer kilovolt-amperes to feeder demand of two

Figure 11. Ratio of dollar value of benefits in excess of additional costs of secondary over primary conductors to total kilowatt feeder capacity

These curves show the value of additional benefit of secondary over primary capacitors for the condition in figure 8, but the benefit is plotted as a ratio of dollars benefit to feeder kilowatt capacity rather than dollars benefit per feeder. These data cover the same conditions as the lower half of figure 8, that is, number 2 conductor size load densities of 10, 50, and 100 kva per mile, and a ratio of transformer kilovolt-amperes to feeder demand of four

Additional benefits include:

1. Released feeder capacity
2. Released distribution-transformer capacity



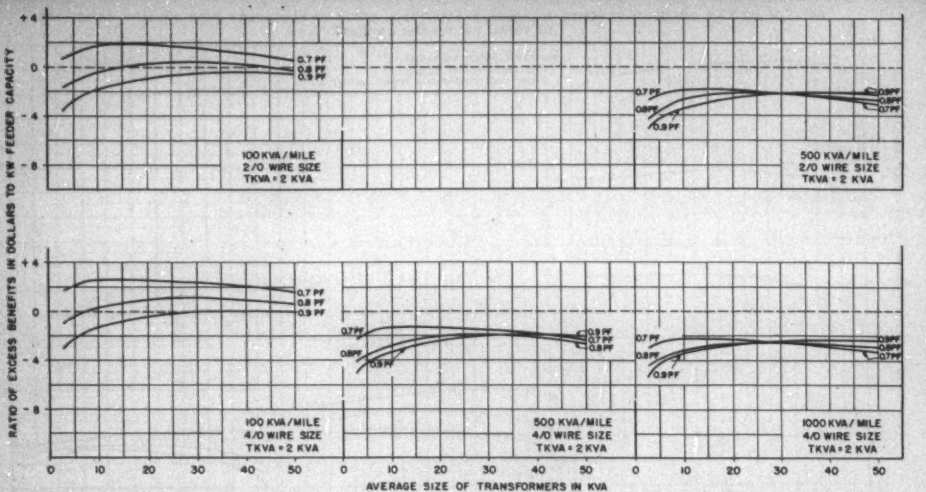


Figure 12 (above). Ratio of dollar value of benefits in excess of additional costs of secondary over primary conductors to total kilowatt feeder capacity

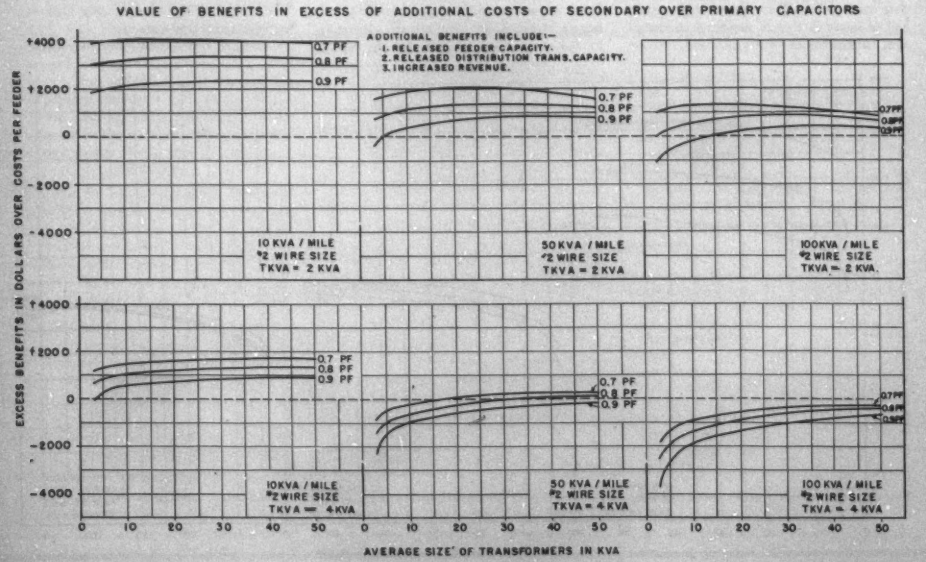
These curves cover the same conditions as those of figure 9, that is, load densities of 100, 500, and 1,000 kva per mile, conductor sizes of 2/0 and 4/0, etc., but (similar to figures 10 and 11) the additional benefits are plotted as dollars benefit per kilowatt of feeder capacity rather than per feeder

Additional benefits include:

1. Released feeder capacity
2. Released distribution-transformer capacity

Figure 13

These curves cover the same set of conditions as curves of figure 8 except that the additional benefit of increased revenue has been added. In this case the additional benefits have been plotted in dollars per feeder. It should be noted in comparing these data with those of figure 8 that the item of additional revenue still leaves the application of secondary capacitors somewhat doubtful except at light load densities. It may be noted, however, that for a ratio of transformer kilovolt-amperes to feeder demand of two, the secondary capacitors appear to somewhat of an advantage at all three of the load densities considered



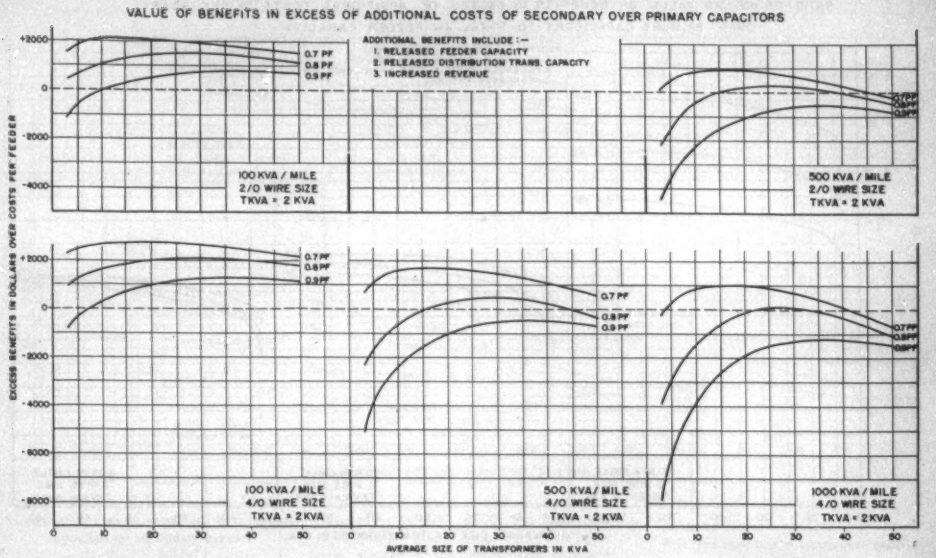
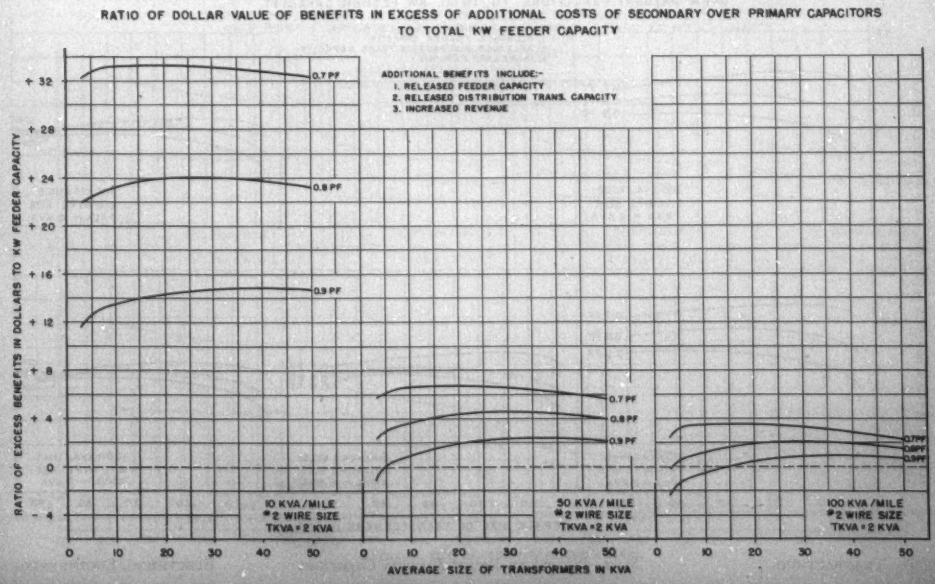


Figure 14 (above)

The data plotted here are entirely similar to those of figure 9 and cover a similar set of conditions, but include the additional benefit of increased revenue. The additional benefits of primary over secondary capacitors have been plotted in this case as dollars benefit per feeder. Here again it will be noted that the item of additional revenue does not greatly change the over-all picture as shown in figure 9. Secondary capacitors here appear to be attractive only at the load density of 100 kva per mile, except at low power factors

Figure 15 (below)

The data plotted here cover a similar set of conditions as those plotted in figure 10, except the additional item of increased revenue has been included in the benefits. As in figure 10 the value of additional benefit of primary over secondary capacitors has been plotted as total dollars benefit per kilowatt of feeder capacity, rather than per feeder



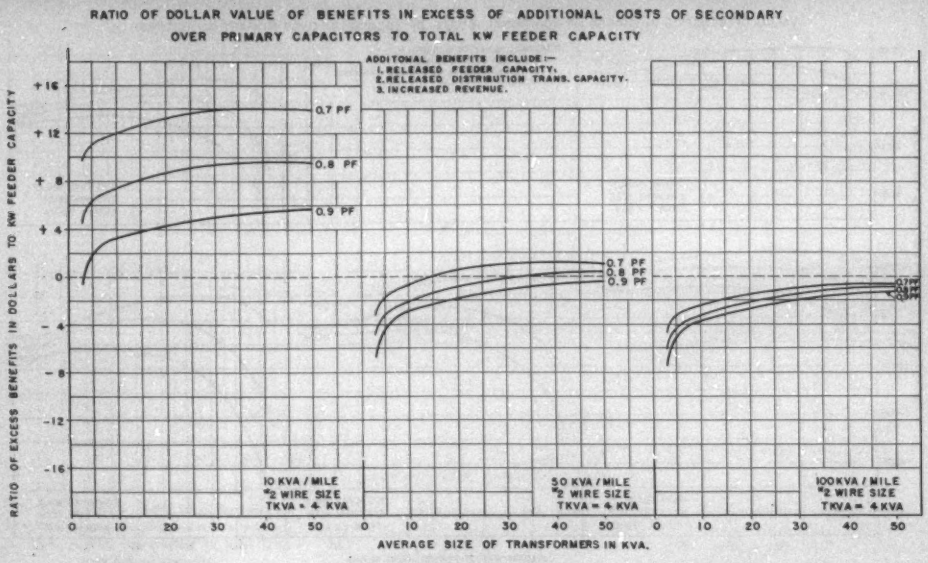


Figure 16 (above)

The data plotted here cover the same set of conditions as figure 11 except that the item of additional revenue has been included as a benefit. As in figure 11, the value of additional benefit of primary over secondary capacitors has been plotted as total dollars benefit per kilowatt of feeder capacity, rather than per feeder

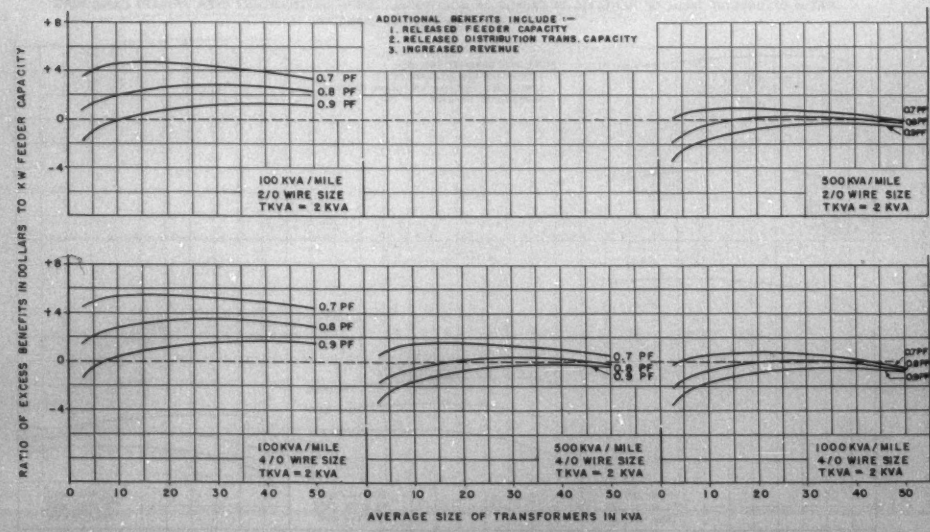

RATIO OF DOLLAR VALUE OF BENEFITS IN EXCESS OF ADDITIONAL COSTS OF SECONDARY
OVER PRIMARY CAPACITORS TO TOTAL KW FEEDER CAPACITY
ADDITIONAL BENEFITS INCLUDE :—
1. RELEASED FEEDER CAPACITY
2. RELEASED DISTRIBUTION TRANS. CAPACITY
3. INCREASED REVENUE
RATIO OF EXCESS BENEFITS IN DOLLARS TO KW FEEDER CAPACITY
+8
+4
0
-4
0.7 PF
0.8 PF
0.9 PF
100 KVA / MILE
2/0 WIRE SIZE
TKVA = 2 KVA
500 KVA / MILE
2/0 WIRE SIZE
TKVA = 2 KVA
100KVA / MILE
4/0 WIRE SIZE
TKVA = 2 KVA
500 KVA / MILE
4/0 WIRE SIZE
TKVA = 2 KVA
1000 KVA / MILE
4/0 WIRE SIZE
TKVA = 2 KVA
0 10 20 30 40 50
AVERAGE SIZE OF TRANSFORMERS IN KVA

Figure 17

The data plotted here cover the same set of conditions as considered in figure 12 except that the item of additional revenue has been included as an additional benefit. The value of additional benefit of primary over secondary capacitors has been plotted as total dollars benefit per kilowatt of feeder capacity, rather than per feeder

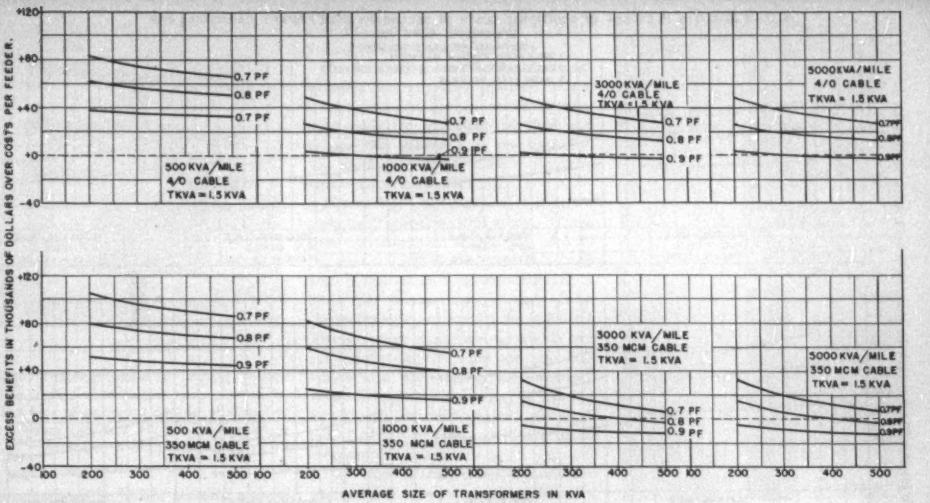


Figure 18 (above). Value of benefits in excess of additional costs of secondary over primary capacitors for secondary network

Figures 8 to 17 have summarized the results of a comparative analysis of primary over secondary capacitors on overhead lines covering a wide range of conditions. The data plotted here are similar to the foregoing but cover the secondary network application. Total additional benefits include (1) released feeder capacity, (2) released distribution transformer capacity, and have been plotted in dollars per feeder. Load densities were assumed to be 500, 1,000, and 3,000 and 5,000 kva per mile. The primary 13-kv cable was assumed to be alternatively 4/0 and 350,000 circular mil. Ratio of transformer kilovolt-amperes to diversified demand was assumed to be 1.5

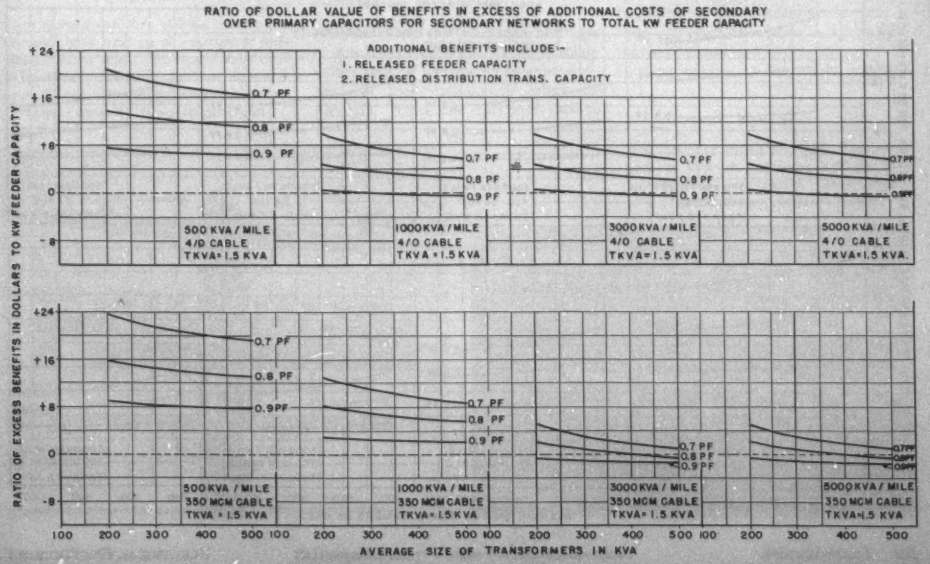
Average size of distribution transformers ranged from 200 to 500 kva. It may be noted that, except at a load density of 500 kva per mile the secondary capacitor appears to be at somewhat of an advantage over the primary capacitor

Additional benefits include:

1. Released feeder capacity
2. Released distribution-transformer capacity

Figure 19

The set of data considered here is the same as that considered in figure 18 except that the value of additional benefit of secondary over primary capacitors has been plotted as dollars benefit per kilowatt of feeder capacity rather than dollars benefit per feeder


RATIO OF DOLLAR VALUE OF BENEFITS IN EXCESS OF ADDITIONAL COSTS OF SECONDARY OVER PRIMARY CAPACITORS FOR SECONDARY NETWORKS TO TOTAL KW FEEDER CAPACITY
ADDITIONAL BENEFITS INCLUDE:-
1. RELEASED FEEDER CAPACITY
2. RELEASED DISTRIBUTION TRANS. CAPACITY
RATIO OF EXCESS BENEFITS IN DOLLARS TO KW FEEDER CAPACITY
+24
+16
+8
0
-8
0.7 PF
0.8 PF
0.9 PF
500 KVA / MILE
4/0 CABLE
TKVA = 1.5 KVA
1000 KVA / MILE
4/0 CABLE
TKVA = 1.5 KVA
3000 KVA / MILE
4/0 CABLE
TKVA = 1.5 KVA
5000 KVA / MILE
4/0 CABLE
TKVA = 1.5 KVA.
500 KVA / MILE
350 MCM CABLE
TKVA = 1.5 KVA
1000 KVA / MILE
350 MCM CABLE
TKVA = 1.5 KVA
3000 KVA / MILE
350 MCM CABLE
TKVA = 1.5 KVA
5000 KVA / MILE
350 MCM CABLE
TKVA = 1.5 KVA
100 200 300 400 500 100 200 300 400 500 100 200 300 400 500 100 200 300 400 500
AVERAGE SIZE OF TRANSFORMERS IN KVA

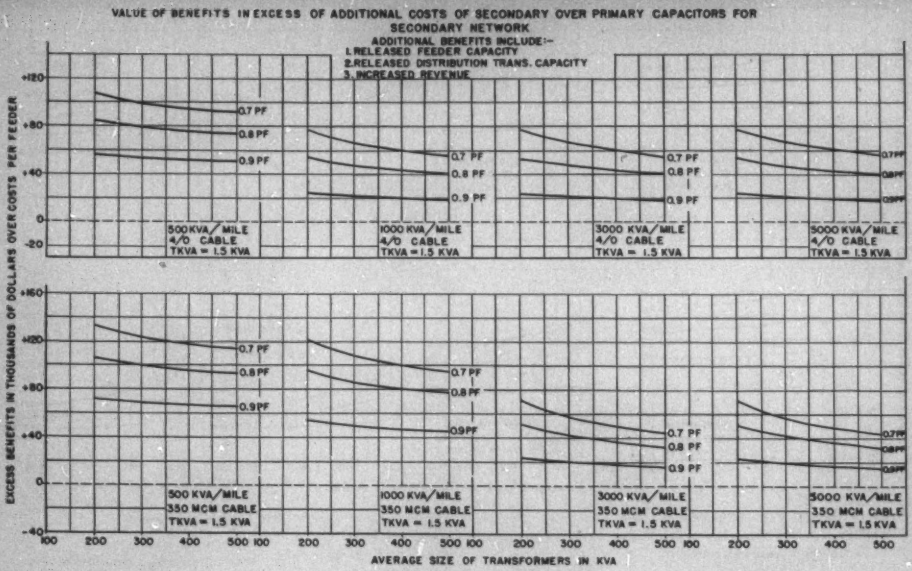

VALUE OF BENEFITS IN EXCESS OF ADDITIONAL COSTS OF SECONDARY OVER PRIMARY CAPACITORS FOR SECONDARY NETWORK
ADDITIONAL BENEFITS INCLUDE:-
1. RELEASED FEEDER CAPACITY
2. RELEASED DISTRIBUTION TRANS. CAPACITY
3. INCREASED REVENUE
EXCESS BENEFITS IN THOUSANDS OF DOLLARS OVER COSTS PER FEEDER
+120
+80
+40
0
-20
0.7 PF
0.8 PF
0.9 PF
500 KVA / MILE 4/0 CABLE TKVA = 1.5 KVA
1000 KVA / MILE 4/0 CABLE TKVA = 1.5 KVA
3000 KVA / MILE 4/0 CABLE TKVA = 1.5 KVA
5000 KVA / MILE 4/0 CABLE TKVA = 1.5 KVA
+160
+120
+80
+40
0
-40
500 KVA / MILE 350 MCM CABLE TKVA = 1.5 KVA
1000 KVA / MILE 350 MCM CABLE TKVA = 1.5 KVA
3000 KVA / MILE 350 MCM CABLE TKVA = 1.5 KVA
5000 KVA / MILE 350 MCM CABLE TKVA = 1.5 KVA
100 200 300 400 500 100 200 300 400 500 100 200 300 400 500 100 200 300 400 500
AVERAGE SIZE OF TRANSFORMERS IN KVA

Figure 20 (above)

This set of curves is similar to those of figure 18 except that the item of increased revenue has been included as a benefit. Here the value of additional benefits of secondary over primary capacitors has been plotted in total dollars benefit per feeder

It may be noted that the item of increased revenue increases the total benefit to such an extent that the secondary capacitors appear to be of a considerable advantage in all cases considered over the primary capacitors

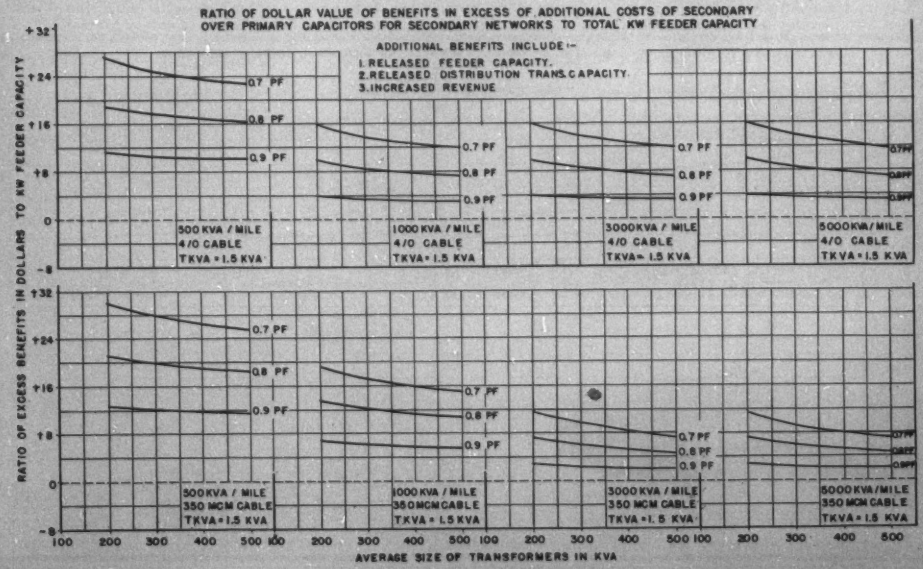

RATIO OF DOLLAR VALUE OF BENEFITS IN EXCESS OF ADDITIONAL COSTS OF SECONDARY OVER PRIMARY CAPACITORS FOR SECONDARY NETWORKS TO TOTAL KW FEEDER CAPACITY
ADDITIONAL BENEFITS INCLUDE:-
1. RELEASED FEEDER CAPACITY.
2. RELEASED DISTRIBUTION TRANS. CAPACITY.
3. INCREASED REVENUE
RATIO OF EXCESS BENEFITS IN DOLLARS TO KW FEEDER CAPACITY
+32
+24
+16
+8
0
-8
0.7 PF
0.8 PF
0.9 PF
500 KVA / MILE 4/0 CABLE TKVA = 1.5 KVA
1000 KVA / MILE 4/0 CABLE TKVA = 1.5 KVA
3000 KVA / MILE 4/0 CABLE TKVA = 1.5 KVA
5000 KVA / MILE 4/0 CABLE TKVA = 1.5 KVA
500 KVA / MILE 350 MCM CABLE TKVA = 1.5 KVA
1000 KVA / MILE 350 MCM CABLE TKVA = 1.5 KVA
3000 KVA / MILE 350 MCM CABLE TKVA = 1.5 KVA
5000 KVA / MILE 350 MCM CABLE TKVA = 1.5 KVA
100 200 300 400 500 100 200 300 400 500 100 200 300 400 500 100 200 300 400 500
AVERAGE SIZE OF TRANSFORMERS IN KVA

Figure 21 (below)

The data plotted here are similar to that of figure 20 except that the item of increased revenue has been included as a benefit. Similar to figure 20 the data here have been plotted as total dollars benefit per kilowatt of feeder capacity

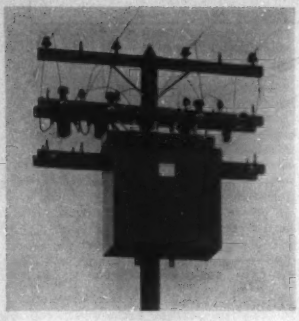


Figure 22

This illustration shows a 180-kva primary line capacitor for urban type of feeders. This type of equipment consists of a number of indoor capacitor units mounted inside a ventilated weatherproof housing

was assumed to be ten per cent and on the 13.8-kv underground secondary network feeders five per cent except where the thermal capacity of the cable would be exceeded. With this criteria for line capacity and the range of load densities used, the overhead lines varied in length from 2.2 miles to 17.8 miles while the underground network feeders varied in length from 3.5 miles to 12.7 miles. Similarly kilovolt-ampere peak loads varied from 173 kva to 2,520 kva on the overhead lines and from 3,500 to 9,000 kva on the network feeders.

For each case considered, additional kilowatt line capacity, released transformer capacity, and increased revenue were evaluated in dollars per line and dollars per kilowatt of line capacity. The methods used for these evaluations are tabulated in the appendix.

Figure 3 gives the capacitor installed costs used in making this study. These were approximately selling price plus 20 per cent for installation. On this basis 4-kv capacitors have an installed cost of $7.55 per kilovolt-ampere and 13-kv capacitors have an installed cost of $12.60. The secondary units have a variable cost per kilovolt-ampere, since the unit cost varies with size, but on the secondary network application the cost is fixed at $22.40 per kilovolt-ampere, since all banks of 208-volt capacitors are in increments of 5-kva units.

The value of transformer capacity also varies with size of installation. The values used in this study for the radial overhead line and underground network transformer costs are summarized in figure 4 and figure 6, respectively.

The unit line costs used are:

Three-phase number 2 4-kv overhead—$2,763 per mile
Three-phase number 2/0 4-kv overhead—$3,540 per mile
Three-phase number 4/0 4-kv overhead—$4,450 per mile
Three-phase number 4/0 13.8-kv cable—$17,400 per duct mile
Three-phase 350,000-circular-mil 13.8-kv cable—$20,100 per duct mile

These values are based upon averages of actual installed costs. Their absolute values may be in error for specific localities but their comparative values are accurate. These line costs were used to determine the value of a kilowatt of line capacity in each case.

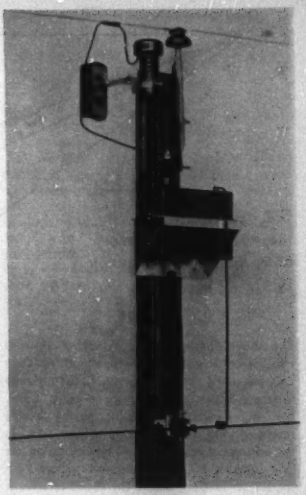


Figure 24

This is a typical installation of a 15-kva primary-line capacitor for single-phase rural service

Examination of Results

In order to obtain any reasonable appraisal of the merits of the secondary capacitor on the distribution system, it was necessary to analyze a fairly wide range of circuit and load conditions. To present adequately the results a rather

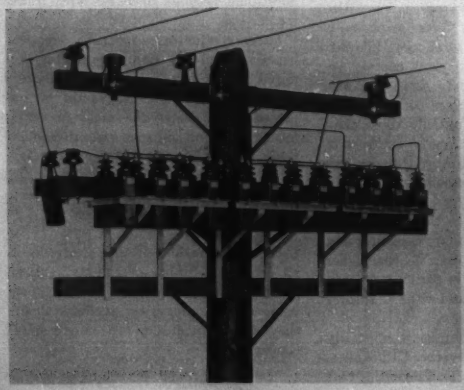
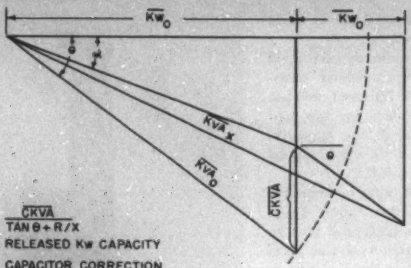


Figure 23

Here is shown another 180-kva primary-line capacitor bank made up of a number of individual outdoor units. This type of installation is functionally identical with that shown in figure 22 but is frequently preferred because it has a somewhat lower installed cost

Figure 25

This illustration shows a 150-kva three-phase bank of 208-volt capacitors installed in a building vault for reactive kilovolt-ampere correction on a secondary network



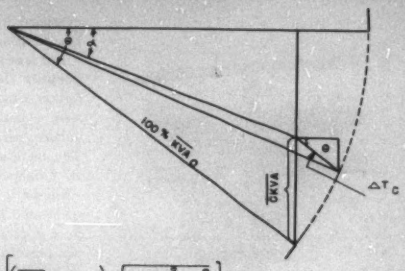
$\overline{Kw_0} = \frac{\overline{CKVA}}{TAN\,\theta + R/X}$

$\overline{Kw_0}$ = RELEASED Kw CAPACITY

$\overline{CKVA}$ = CAPACITOR CORRECTION
R = LINE RESISTANCE
X = LINE RESISTANCE

Figure 26

The above diagram shows the vector relations existing between the pertinent quantities when capacitors are used to release feeder capacity where voltage drop is the limiting factor. For any particular capacitor having a **kva** rating of **Ckva** the above relation for Δkw_0 is the additional key which can be carried on the line without exceeding the voltage drop on the feeder existing before the capacitors were applied. In the above relation values of **kva, kw,** or **Ckva** may be expressed either as such or as percentages



$\overline{\Delta T_c} = \left[\left(\frac{\overline{CKVA}}{KVA_0} \sin\theta - 1\right) + \sqrt{1 - \frac{\overline{CKVA}^2}{KVA_0^2}\cos^2\theta}\right] \overline{KVA}_0$

$\overline{\Delta T_c}$ = RELEASED KVA CAPACITY
$\overline{CKVA}$ = CAPACITOR KVA CORRECTION
KVA = NOMINAL KVA RATING

Figure 27

The above diagram shows the vector relations existing between the pertinent quantities when capacitors are used to release capacity when kilovolt-ampere demand is the limiting factor. For any capacitor correction having a rating of **Ckva**, the above relation for ΔT_c is the additional kilovolt-ampere which can be carried at the initial load power factor without exceeding the nominal 100 per cent **kva**. In the above relation the values of **kva**, or **Ckva** may be expressed either as such or as percentages

large number of curves were necessary since five variables were involved—that is, power factor, load density, conductor size, diversity, and average transformer size. Moreover, it seemed necessary to prepare the results both considering and not considering increased revenue as a benefit since this item is controversial.

To show clearly when the secondary capacitor is to be preferred, it is necessary only to plot the difference in dollars between the capital value of the additional benefits which secondary capacitors have over primary capacitors and the capital value of the additional costs of secondary over primary capacitors. If the additional benefits exceed the additional costs, the secondary capacitor is a sound investment.

In figures 8 to 21, therefore, this difference between additional benefits and additional costs has been plotted as a function of the various circuit and load conditions. It has been plotted, first in dollars per feeder, and second, in dollars per kilowatt of feeder capacity. It seemed advisable to present the picture both ways since the feeders varied considerably in length and loading, they being alike only in maximum allowable voltage drop.

In examining figures 8 to 21, note that the dollar benefits or deficiency consist of the sum of the following items:

1. Capital value of additional distribution transformer capacity.
2. Capital value of additional feeder capacity.
3. Capital value of additional revenue (capitalized on the basis of 12.5 per cent annual carrying charge).

As stated above, the data were also calculated omitting the third item of revenue. Figures 8 to 17 cover the overhead lines studied, and figures 18 to 21 cover underground secondary networks. Figures 13, 14, 15, 16, 17, 20, and 21 include the item of additional revenue as a benefit and the others omit it.

Consider the comparative effect of the several variables individually. First consider the network versus the overhead line. With a few minor exceptions all networks favor the secondary capacitor whether the item of revenue is allowed or not. With many of the overhead lines, on the other hand, the secondary capacitor cannot be justified. The reasons for this are more or less evident. The value of released transformer capacity in a secondary network, in most cases, is worth considerably more than transformer capacity on poles. Also underground primary feeder capacity is worth considerably more per kilowatt than overhead lines in many cases. Accentuating these effects there are also the contributing factors that 13.8-kv capacitors cost substantially more than do 4-kv units. Also the lowest cost of all secondary capacitors is the five-kva unit used on the secondary network (see figure 3).

In virtually all cases the lower power factors favor the secondary capacitor to a much greater extent than do the higher power factors. This is particularly true at light load densities and with the smaller conductor sizes.

The effect of load density is especially interesting. On the overhead lines, it is only at the very light load densities that secondary capacitors can be justified, in many cases even though additional revenue is allowed. In the case of the network, while secondary unit nearly always is justified, the maximum benefits likewise occur at the lighter load densities.

The influence of transformer size varies. On overhead lines, in many cases the additional benefits increase with size of transformer, while in other cases there is an optimum size varying from 10 to 30 kva. With the networks the value of additional benefits decrease with transformer size.

Large conductors appear to offer less benefits than do small conductors on radial feeders, but on the network feeders the reverse is true. As would be expected, the greater the ratio of transformer kilovolt-amperes to diversified peak kilovolt-ampere demand, the less attractive are secondary capacitors.

Conclusions

While the results of this study, as in all economic studies of this type, have greater comparative value than absolute value when applying to specific systems, they do establish the following general conclusions:

1. On underground secondary networks,

particularly those served from primary voltages of 11-kv or greater, the secondary capacitor appears to have an important field of application.

2. On conventional overhead systems, particularly those having primary voltages of 6,900 volts or less, the secondary capacitor has a very limited field of application. It is doubtful if secondary capacitors can be proved in on any overhead line except in cases of rather low power factor. However, on overhead systems incorporating banked secondaries, since many of the inherent advantages of secondary capacitors on low-voltage networks are duplicated, the secondary capacitor in many cases may easily be proved in.

3. Low power factors establish conditions on any distribution system—network or radial—which strongly favor secondary capacitors.

4. Secondary capacitors must be applied with considerable care—much more so than primary capacitors—if the hypothetical calculated benefits are to be realized. Accurate setting of the contact-making voltmeter and the compensator together with proper location and size of the secondary units are very essential to obtain the calculated additional benefits.

5. If economic analysis shows that a secondary capacitor adjacent to a distribution transformer cannot be justified, only a cursory analysis is necessary to show that, under the same circuit and load conditions, a large number of smaller units adjacent to meter boxes likewise cannot be justified. This is owing to the rapid increase in cost per kilovolt-ampere as the size of the unit comes down (see figure 3). It is somewhat doubtful under any circuit or load conditions if a plan incorporating a number of small units located at meter boxes could ever be justified.

Appendix

Releasing System Capacity With Capacitors Where Voltage Drop Is the Limiting Factor

The kilowatt carrying capacity of any part of a system, such as a distribution feeder, where the limitation on capacity is voltage drop, is:

$$\boldsymbol{kw}_0 = \frac{10\ \boldsymbol{kv}^2\ v}{R + X \tan\theta} \qquad (1)$$

v = allowable per cent volts drop
R = total resistance in ohms
X = total reactance in ohms
θ = uncorrected power factor angle
$\boldsymbol{kv}$ = line kilovolts
$\boldsymbol{kw}_0$ = kilowatt capacity

If the allowable drop v is increased by an amount Δ_v per cent for one reason or another, the increase in kilowatt capacity is

$$\Delta\boldsymbol{kw}_0 = \frac{10\ \boldsymbol{kv}^2\ \Delta v}{R + X \tan\theta} \text{(refer to figure 26)} \qquad (2)$$

If a primary capacitor is applied at the end of the line (or at a distance corresponding to R and X), the per cent voltage rise due to the capacitor is

$$\Delta v = \frac{\boldsymbol{Ckva}\ X}{10\ \boldsymbol{kv}^2} \qquad (3)$$

$\boldsymbol{Ckva}$ = kilovolt-amperes of capacitor

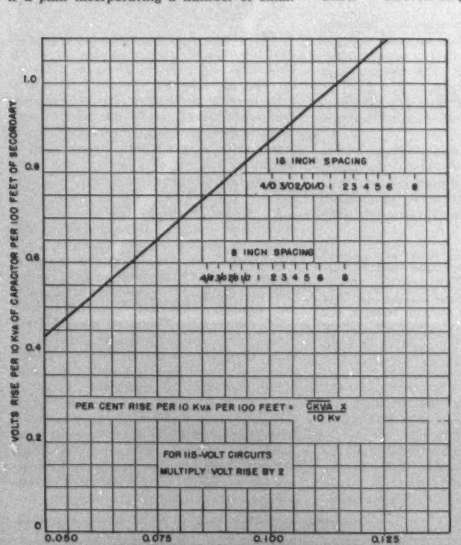

VOLTS RISE PER 10 Kva OF CAPACITOR PER 100 FEET OF SECONDARY
1.0
0.8
0.6
0.4
0.2
0
16 INCH SPACING
4/0 3/0 2/0 1/0 1 2 3 4 5 6 8
8 INCH SPACING
4/0 3/0 2/0 1/0 1 2 3 4 5 6 8
PER CENT RISE PER 10 Kva PER 100 FEET = CKVA X / 10 Kv
FOR 115-VOLT CIRCUITS
MULTIPLY VOLT RISE BY 2
0.050
0.075
0.100
0.125
OHMS REACTANCE PER 1000 FEET OF SECONDARY

FIGURE 28 VOLTAGE RISE ON 230-VOLT, 3-WIRE, 1-PHASE, SECONDARIES PER 10 Kva OF 230-VOLT CAPACITOR

Figure 28

This curve shows the voltage rise on 230-volt three-wire single-phase secondaries per ten kva of 230-volt capacitor. For 115-volt secondaries the voltage rise should be multiplied by two

and the resultant kilowatt capacity of the line is:

$$\boldsymbol{kw}_2 = \frac{10\ \boldsymbol{kv}^2\ (v + \Delta v)}{X \tan\theta_0 + R} \qquad (4)$$

$$= \frac{10\ \boldsymbol{kv}^2\ v + X\ \boldsymbol{Ckva}}{X \tan\theta_0 + R}$$

A specified amount of primary capacitor correction gives a definite voltage rise on the feeder. If this same kilovolt-amperes of primary correction is applied to the secondary side of the distribution transformers and if it is uniformly distributed in proportion to the distribution transformer capacity, there will be an additional per cent voltage rise due to the transformer reactance of

$$\Delta v_t = X_t \frac{\boldsymbol{Ckva}}{\boldsymbol{Tkva}} \qquad (5)$$

X_t = transformer reactance in per cent
$\boldsymbol{Ckva}$ = total capacitor correction in kilovolt-amperes
$\boldsymbol{Tkva}$ = total installed transformer kilovolt-amperes

This additional voltage rise is not effective in increasing the line kilowatt capacity, however, unless it is confined to that portion of the feeder beyond the transformer location at which the feeder voltage drop is equal to the voltage rise in the transformer effected by the capacitor. If this method of applying the secondary unit is adopted, the additional voltage rise will be:

$$\Delta v_t = X_t \frac{\boldsymbol{Ckva}}{(\boldsymbol{Tkva})K} \qquad (6)$$

where K is defined by the relation

$$K^3 - K + \frac{(\boldsymbol{Ckva})}{(\boldsymbol{Tkva})} \frac{X_t}{10} = 0 \qquad (7)$$

The additional increase in primary line kilowatt capacity accruing from secondary over primary capacitors is therefore:

$$\Delta\boldsymbol{kw}_t = \frac{20\ \boldsymbol{kv}^2\ \boldsymbol{Ckva}\ X_t}{\boldsymbol{Tkva}\ K(\tan\theta + R/X)X} \qquad (8)$$

If the peak diversified demand on the feeder is $\boldsymbol{Kva}_0$ before correction, then

$$\boldsymbol{Tkva} = n\ \boldsymbol{Kva}_0 \qquad (9)$$

where n is the ratio of installed transformer capacity to diversified demand. Also:

$$\boldsymbol{Ckva} = \boldsymbol{Rkva} \qquad (10)$$

where $\boldsymbol{Rkva}$ is the average reactive kilovolt-amperes on the feeder during a 24-hour period.

Figures 5 and 7 are plots of equation 5 for transformers on overhead lines and secondary networks, respectively. These curves show the voltage rise effected by capacitors for various amounts of capacitor correction. It is assumed in each case that the feeder power factor has been corrected to unity and that $n = 2$, a fairly representative value for most distribution feeders. It may be noted that the maximum voltage rise is about one per cent for transformers on overhead lines and about two per cent for transformers in secondary networks.

Releasing System Capacity With Capacitors Where Temperature Rise Is the Limiting Factor

The capacity of generators, transformers, etc., is usually limited by temperature rise, that is, kilovolt-ampere demand, rather than by voltage drop. Figures 26 and 27 illustrate the difference in these two limiting factors vectorially. In figure 26, Δkw_0 is the additional kilowatts that can be carried after adding capacitor correction $Ckva$, with exactly the same voltage drop as obtained before correction. Δkw_0 is always assumed to be added at the uncorrected power factor angle, θ. In figure 27 Δkva is the additional kilovolt-amperes at power factor θ which can be added after correction without the net resultant kilovolt-amperes exceeding the initial.

In general, for a given amount of capacitor correction, the released capacity, where voltage drop is the limiting factor, usually substantially exceeds that where kilovolt-ampere demand is the limiting factor.

In figure 26,

$$\Delta kw_0 = \frac{Ckva}{\tan\theta + R/X} \qquad (11)$$

The values R and X are resistance and reactance from the substation to any particular capacitor installation having a value $Ckva$ and Δkw_0 is the released capacity for that particular installation: or R and X may be considered the resistance and reactance to the load center if $Ckva$ equals the total capacitor correction. In equation 11, Δkw_0 and $Ckva$ may be expressed either as kilowatts and kilovolt-amperes or as per cent.

In figure 27,

$$\Delta Kva = \left[\left(\frac{(Ckva)}{(Tkva)K}\sin\theta - 1\right) + \sqrt{1 - \frac{(Ckva)^2}{(Tkva)^2K}\cos^2\theta}\right] Tkva\,K \qquad (12)$$

$Ckva$ = capacitor correction
Kva = released kilovolt-ampere capacity
$Tkva$ = transformer kilovolt-ampere capacity
θ = uncorrected power-factor angle

On a percentage basis equation 12 becomes

$$\Delta T_c = (C\sin\theta - 100) + \sqrt{100^2 - C^2\cos^2\theta} \qquad (13)$$

ΔT_c = per cent released capacity
C = per cent capacitor correction
θ = uncorrected power-factor angle

In equation 12, ΔT_c and C are percentages of the kilovolt-ampere capacity of the transformer receiving correction. Equation 13 obviously applies to any size of transformer, substation, etc.

The value ΔT_c may also be calculated as a function of power-factor angles before and after correction:

$$\Delta T_c = -100\cos\theta[\cos\theta + \sin\theta\tan\alpha] + 100\cos^2\theta\sqrt{1 + 2\tan\theta\tan\alpha - \tan^2\alpha + \frac{\tan^2\theta}{\cos^2\theta}} \qquad (14)$$

θ = power-factor angle before correction
α = power-factor angle after correction

Increase in Revenue

The increase in kilowatt-hour output effected by the voltage rise as calculated in equation 6 is usually assumed to increase as the 1.6 power of increase in average voltage level over a 24-hour period. On this basis the additional kilowatt-hours due to secondary capacitors as compared with primary capacitors will be

$$\Delta kw\text{-}hr = \left[\left(\frac{\dfrac{(Ckva)}{(Tkva)K}\dfrac{X_t}{2} + 100}{100}\right)^{1.6} - 1\right] \times kw_0 \times \text{L.F.} \times 8{,}760 \qquad (15)$$

kw_0 = peak feeder kilowatts
L.F. = load factor

This additional kilowatt-hour output is usually evaluated at $0.02 per kilowatt-hour and capitalized at 12.5 per cent per annum.

Discussion

J. D. Stacy (General Electric Company, Pittsfield, Mass.): Mr. Starr's excellent paper re-emphasizes the extensive application for capacitors on central station systems. It is interesting to note that a large number of utilities throughout the country have applied capacitors with considerable savings—

1. Because of improvement of voltage conditions which has deferred installation of new feeders, feeder positions, cable, etc.
2. Because of release of substation capacity.
3. Due to reduced losses.

This extensive application has been the result of several important factors:

First, the improvements in capacitor design and reliability which have been effected during the last 10–12 years.

Secondly, the simultaneous marked reductions in installed cost of capacitors during the same period.

Capacitor design improvements have covered not only improvements in paper, foil, and the other solid materials used, but principally the substitution of chlorinated diphenyl for the oil previously used. The new liquid has:

(a) Reduced the size and weight of capacitors because of its considerably higher dielectric constant compared with that of oil.

(b) Increased the dielectric strength not only because of its own higher dielectric strength, but because of the improved distribution of voltage stress through the dielectric resulting from the fact that the dielectric constant of liquid and cellulose are practically the same.

In addition, careful attention to the process of vacuum drying and impregnation has been a considerable factor in bringing quality to its present high level.

As a consequence of these factors and the standardization of ratings, capacitor installed costs have been reduced sharply during the last ten years. The average cost per kilovolt-ampere of capacitors of all voltages is now approximately 36 per cent of that in effect in 1929—a reduction of 64 per cent.

L. M. Olmsted (Duquesne Light Company, Pittsburgh, Pa.): Mr. Starr's paper very ably indicates the field in which secondary shunt capacitors are more attractive economically than primary capacitors. In order to secure the utmost advantage for the secondary capacitors, he has assumed that the capacitors will be used only on transformers far enough from the feeding point that the rise in voltage caused by the capacitive current will not raise the secondary voltage above that of the transformers at the feeding point. In this way he makes effective the additional voltage correction through the reactance of the more remote transformers to offset primary-circuit voltage drop, thereby increasing the load-carrying ability of the primary circuit beyond that possible with the same capacity in primary capacitors.

While such a practice is workable, it would require continual supervision to keep it in proper relationship to the system changes which invariably accompany circuit extensions and load growth. This additional supervision would be a disadvantage, tending to reduce possible economies, particularly on the usual overhead radial system, with numerous small transformers. Underground systems, having larger transformers, generally receive more careful supervision and probably would have the capacitors relocated as required. It is fortunate, therefore, that the field of economic application for secondary capacitors is limited mostly to underground systems.

F. M. Starr: I agree with Mr. Olmsted that the method described in this paper for obtaining some additional feeder kilowatt carrying capacity by means of secondary capacitors, necessitates very careful application engineering, and would require continual supervision and checking. This is one of the intangibles which would tend to discourage the use of secondary capacitors if economic advantage were on the border line.

In closing, I should like to emphasize one further point: In the paper 220-volt capacitors were compared with 4,000-volt capacitors, and 208-volt capacitors were compared with 13,000-volt units. In specific cases it might be desirable to compare, for example, 440-volt capacitors with 6,900-volt units. There are several other comparisons which it might be desirable to make in specific cases. It is well to note, therefore, that any general conclusions drawn here do not necessarily apply in some of these specific comparisons. It is further of interest to note in connection with these comparisons that any very substantial change in the price of capacitors, which might be brought about by some new development, would again change the economics and conclusions of this problem.

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Industrial Notes

Equipment Orders to General Electric Co.—The Delaware Electric Power Co., of Wilmington, Del., has placed orders for its first fleet of 55 trolley coaches with the J. G. Brill Co., and the Mack Mfg. Corp. The order involves about $750,000 and represents one of the largest single purchases of trolley coaches. Forty-nine of the 55 coaches are to be equipped with the new General Electric compound-wound motor, which will provide for electric braking and speed control. The Duluth Superior Transit Co. has ordered ten 40-passenger trolley coaches to be built by the J. G. Brill Co., also to be equipped with compound-wound motors. The purchase is part of a complete modernization program planned cooperatively by the city government and the transit company, which calls for substitution of trolley coaches and buses for all street cars now operated on the system.

Electric Couplings for Diesel Ships.—The Westinghouse Electric & Mfg. Co. has been awarded the first order for electric couplings for American built ships by the Falk Corporation of Milwaukee. The contract covers 16 electric couplings, each rated 2230 hp at 240 rpm and for installation on 4 diesel-propelled cargo ships which the Sun Shipbuilding & Dry Dock Company is building for the U.S. Maritime Commission. There will be 4 Busch Sulzer diesel engines per ship and the electric couplings will be used to connect the engines to the pinion shafts of a two-pinion, single reduction gear unit being manufactured by the Falk Corporation. The principal feature of such an installation is the use of a number of relatively small, high speed, diesel engines in place of one large, slow speed engine. When maneuvering the ship or when it is more economical to use only a part of the engines, the electric coupling provides a means of readily disconnecting one or more engines from the propulsion system.

Large Household Washer Sales.—For the first quarter of this year household washer shipments reached 392,519 units. It was the industry's biggest quarter since the third in 1937, showing an increase of 38 per cent over the total of 284,370 attained in the opening quarter of 1938 and 47 per cent over the final quarter of 1938. Factory shipments of 152,725 washers in March were the highest for any month in two years. The March total was 30 per cent ahead of March 1938 and 17 per cent greater than that for February 1939.

Bartlett to Knoxville, Tenn.—Max C. Bartlett, associate engineer for 15 years with Burns & McDonnell Engineering Co., Kansas City, Mo., has been appointed general manager of the water and lighting department of the municipal utilities at Knoxville, Tenn. Knoxville is the largest city in the TVA territory to acquire TVA power. The water and light will be under one management and will serve suburban territory. The water works pumping station is now being electrified under plans prepared by Burns & McDonnell Engineering Co.

New Plant for Allis-Chalmers.—Contracts have been let to build a new transformer plant in Pittsburgh, to be known as the River plant of the Allis-Chalmers Mfg. Co., Pittsburgh Works. Measuring 416 by 144 feet, the cost, with buildings and equipment, will be about $378,000; operations will start about August 15. In design, the plant will represent the latest manufacturing methods as applied to the production basis—raw material coming in at one end and the finished product going out at the other.

Switch Order to Delta-Star.—The Los Angeles Department of Water & Power has awarded the Delta-Star Electric Co., Chicago, Ill., a contract approximating $95,000 for 287,000-volt, 3-pole disconnecting switches for use on the new transmission line from Boulder Dam to Los Angeles. These switches, for installation at Silver Lake and Victorville, are duplicates of those installed in 1934 for the original lines.

Ward Leonard Moves District Office.—A change in address of the Ward Leonard Electric Company's Philadelphia office has been made to 1600 Arch Street. Frank Beede, formerly of the Chicago office, and for several years attached to the sales engineering department at the factory in Mount Vernon, N. Y., is district manager.

American Steel & Wire Appointments.—Walter F. Munford has been appointed assistant to vice-president (operations) at the main office of the American Steel & Wire Co., Cleveland. Mr. Munford previously was superintendent of the company's works in Cleveland, which includes the largest cold rolled strip mill in the world. H. L. Jenter, formerly assistant superintendent at Cuyahoga, becomes general superintendent of that works, while J. D. Baster becomes superintendent of the cold rolled mills. A. G. Montgomery is now superintendent of the hot mills, and V. H. Leichliter superintendent of the wire mill.

New Sales Agent for B-L Electric.—The Benwood Linze Company, St. Louis, Mo., is now domestic and export sales agent for the B-L Electric Mfg. Co., of St. Louis, Mo., manufacturers of rectifiers. No change in officers, personnel, or corporate structure has been made. At the same time the company has acquired the interests of the Brenkert Light Projection Co., in the manufacture of rectifier equipment.

Sprague Adds New Plant.—The recent purchase by the Sprague Specialties Company of a set of factory buildings in North Adams, Mass., almost doubles the floor space now available in that city for the manufacture of condensers and resistors. Steadily increasing business, both export and domestic, plus the recent introduction of wire wound resistors, push button tuners and many new condenser types, made the expansion advisable. The new plant consists of an office building, three separate manufacturing buildings ranging from 2 to 4 stories high, a power house and 3 warehouses, all located within a mile of the present plant.

Pre-Fabricated Beryllium Alloys.—The Beryllium Corporation of Pennsylvania, Reading, Pa., has completed its new, specially designed facilities for the commercial production of heat-treated beryllium alloys in rod, strip, and wire forms. Hitherto, the company has supplied master alloys only in the ingot and cast form. Now it will be possible to obtain 2–2.25 per cent beryllium-copper, beryllium-nickel and other alloys in the primary fabricated shapes. The alloys have high electrical conductivities and tensile strengths, elastic stability, resistance to fatigue, heat and wear, and uniform hardening characteristics.

Trade Literature

Radio-Interference-Free Insulators.—Bulletin, 6 pp. Describes manufacturing processes and features of "quiet-type" insulators. The R. Thomas & Sons, Co., Lisbon, O.

Indicating Thermometers.—Bulletin 4201, 2 pp. Describes industrial indicating control thermometers designed for low temperature control applications. Wheelco Instruments Co., 1929 So. Halsted St., Chicago.

Motors.—Bulletin 2183-A, 4 pp. Describes "Lo-Maintenance" d-c motors and generators. Bulletin 2125-C, 4 pp., describes "explosion-proof" motors. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Motor Control.—Bulletin, 8 pp. Describes frequency relay, magnetic control for a-c, wound-rotor motors, applicable in numerous industries. The Electric Controller & Mfg. Co., Cleveland, Ohio.

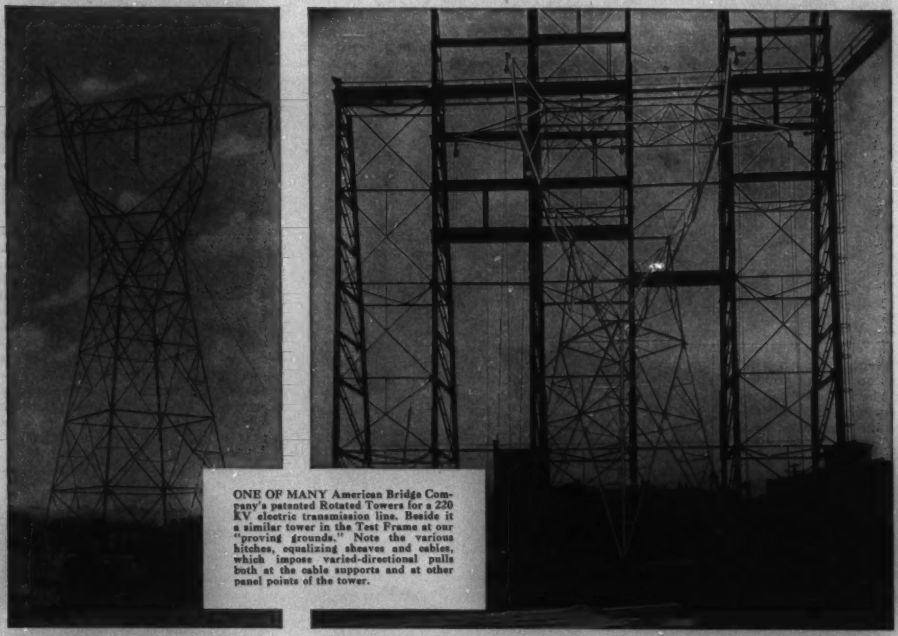
Monel Metal.—Tech. Bulletin T-5, 12 pp. Describes engineering properties of monel; contains revised information on mechanical characteristics. Dev. and Res. Div., The International Nickel Co., Inc., 67 Wall St., New York City.

Electrical Contacts.—Bulletin C-902, 4 pp. Describes various types of silver and precious metal and alloy contacts. Detailed, dimension drawings of the most commonly used types of such contacts are included. Fansteel Metallurgical Corp., North Chicago, Ill.

Galvanized Coatings.—Bulletin 675-G, 8 pp. Describes the results of an investigation to determine satisfactory methods for measuring the weight and uniformity of hot-dip galvanized castings and forgings. Ohio Brass Co., Mansfield, O.

Phosphor Bronze.—Bulletin, 48 pp. Describes characteristics of phosphor bronze and the wide variety of alloys, forms and temper available. Standard and special applications are illustrated, including electrical uses. The Riverside Metal Co., Riverside, N. J. *(Continued on page 10)*

AMERICAN BRIDGE "PROVING GROUNDS" put Line-Towers through the "ACID TEST"



ONE OF MANY American Bridge Company's patented Rotated Towers for a 220 KV electric transmission line. Beside it a similar tower in the Test Frame at our "proving grounds." Note the various hitches, equalizing sheaves and cables, which impose varied-directional pulls both at the cable supports and at other panel points of the tower.

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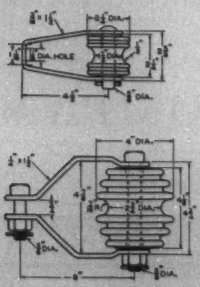
UNITED STATES STEEL

New Products

Stroboscopes.—Two new stroboscopes are announced by General Radio Co., Cambridge, Mass. These are portable units, suitable for both speed measurement and slow-motion studies of rotating and reciprocating mechanisms, such as motors, gears, etc. Speed measurements with an accuracy of ±1 per cent can be made with the

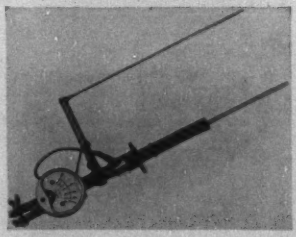
new type 631-B Strobotac which supersedes the older type 631-A. No mechanical or electrical contact with the machine under measurement is required. The stroboscopic light is directed on the machine under measurement and the flashing rate adjusted until the motion appears to be stopped. The speed is then read directly from a scale graduated in rpm. Speeds between 600 rpm and 14,400 rpm are read directly from the scale, which is conveniently located at the top of the instrument. The type 648-A Strobolux is a larger instrument, furnishing about 100 times as much light as the Strobotac. It is used in conjunction with the Strobotac when larger areas are to be illuminated or where background lighting is strong. It can also be used as a light source for single-flash photography.

Insulated Clevis Assemblies.—Three types of insulated clevis assemblies designed for various applications on distribution and rural lines, have been brought out by the Ohio Brass Co., Mansfield, O. One type having a $2^1/_4$-inch spool insulator held by a $4^1/_2$-inch long clevis, is for dead-ending and corner construction on secondary circuits. The other two types have a larger spool insulator, $4^1/_8$ inches long, and are suitable for primary circuit dead-ends and corner



construction, series street lighting circuits and other applications. One of the larger spool assemblies has a closed clevis for through or crossarm bolt mounting. The other has a split clevis with attachment bolt which permits it to be fastened with an eye bolt, hook or cable, or to be bolted directly to the supporting piece. The split clevis is particularly adapted to corner construction, because it is easy to attach and has the necessary flexibility to equalize strains. Both spools are made of wet process porcelain, the same as used for high voltage insulators; a tapered hole distributes the loads more evenly and minimizes the possibility of spool breakage should the bolt be deflected under heavy mechanical load. The clevises are made of steel, hot-dip galvanized. On the two larger assemblies, the clevis is offset near the spool, increasing the flashover value of the units.

High Voltage Insulator Tester.—The live-line tester for testing insulators on overhead high-voltage lines, introduced by Ferranti Electric, Inc., 30 Rockefeller Plaza, New York, N. Y., consists essentially of a small electrostatic voltmeter, mounted on the end of a 12-foot, collapsible, insulated stick,



provided with testing spikes so that the voltmeter may be connected across the insulator units. In using, the operator simply holds the testing stick in his hands, applies the spikes to the insulator under test, and notes the voltmeter reading. The meter may be inclined at various angles to facilitate reading. Safety in operation is assured as all electrical connections are confined to the live end of the testing stick. An article in the "Electrical Review," on Live-Line Testing, reprints of which are available to those interested, includes a detailed description of the device, illustrated with results of tests.

Leakage Resistance Test Set.—The "Megabridge," introduced by Industrial Instruments, Inc., 162 West 23d St., Bayonne, N. J., is an adaptation of the Wheatstone bridge, utilizing an electron ray null indicator. The electron ray tube replaces the delicate galvanometer commonly used as a null detector. Operating entirely from the a-c power line, the Megabridge has a self-contained d-c supply for the bridge circuit and the electron ray tube. Fluctuations of line voltage or tube variations do not affect the calibration. Applications include

rapid and accurate testing of widely varied electrical equipment, insulating materials of all kinds, and indicating moisture content in lumber, paper, etc.

Frequency Controller.—A new Micromax frequency controller, industrial type, introduced by the Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, provides the isolated generating plant with automatic control of frequency which heretofore has been thought feasible only for large central stations on interconnected systems. In one compact case is combined a Micromax frequency indicator and recorder with an automatic controller, a simple, relatively inexpensive arrangement which omits the refinements necessary for the big stations on interconnected systems.

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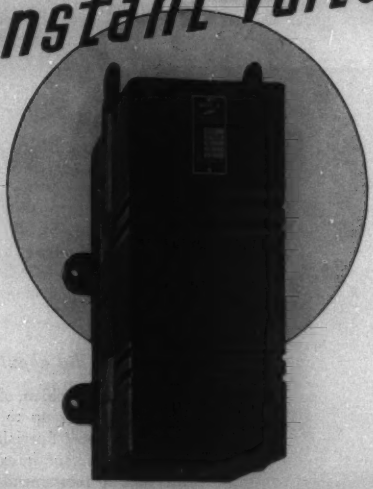
UNITED STATES STEEL

Constant Voltage



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Trade Literature

(Continued from page 8)

Fluorescent Tube Canopies.—Bulletin ML-19, 8 pp. Describes 25 different models of the new fluorescent tube canopies, ranging from a single 15-watt model to a two-tube 80-watt model, of 20-, 26-, 38- and 50-inch length, and for overhead, table or bench mounting. The Fostoria Pressed Steel Corp., Fostoria, O.

Welding Control.—Bulletin WLD 5, 20 pp. A study of resistance welding, machines required and control equipment. Describes the various types of resistance welders used in industry and the problems encountered in the application of all kinds of control to them. Square D Co., Milwaukee, Wis.

Oil Circuit Breakers.—Bulletin 63, 8 pp. Describes 7.5 to 15-kv oil circuit breakers, featuring rapid spring-actuated control mechanisms and expulsion chamber are extinguishing devices; applicable to protection of feeders, transmission lines, industrial loads and station tie-ins. Pacific Electric Mfg. Corp., 5815 Third St., San Francisco, Calif.

Crane Equipment.—Bulletin C 5, "Electrical Equipment for Cranes." Describes complete electrical equipment necessary for overhead traveling crane operation; covers motors of all types, and application of solenoid operated brakes, thrustor-operated brakes, many types of manual drum controllers, etc. Harnischfeger Corp., 4400 W. National Ave., Milwaukee, Wis.

Instruments.—Catalog 48, 16 pp. Describes switchboard instruments, round and rectangular types, including d-c milliammeters, ammeters, voltmeters, millivoltmeters, a-c ammeters, voltmeters, single-phase and poly-phase wattmeters, frequency meters, power factor meters, synchroscopes, and three-phase ammeters. Roller-Smith Co., Bethlehem, Pa.

Air Circuit Breakers.—Bulletin 1237, "Recent Trends in the Use of Sectionalizing Circuit Breakers in the Anthracite Field." Describes a typical sectionalizing plan for a large, eastern Pennsylvania anthracite mine, which is fed from three substations and employs fourteen sectionalizing circuit breakers. I-T-E Circuit Breaker Co., 19th & Hamilton Sts., Philadelphia, Pa.

Fluorescent Tube Reflectors.—Bulletin Sec. 1-C, 16 pp. Describes reflector units for fluorescent tubes, applicable to localized industrial lighting. Includes both flood and concentrating 3-light units, as well as those utilizing the new 48-inch fluorescent tube. All units are now available for d-c as well as a-c use. The Miller Co., Meriden, Conn.

Solenoid-Operated Breakers.—Bulletin 33-123, 4 pp. Describes a solenoid operating mechanism for fast reclosing of high-voltage circuit breakers used in conjunction with carrier-current or high-speed relays. Such relaying and fast reclosing breakers are said to make possible 25 to 50 per cent increase in line capacity over an existing system by increasing the system stability. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

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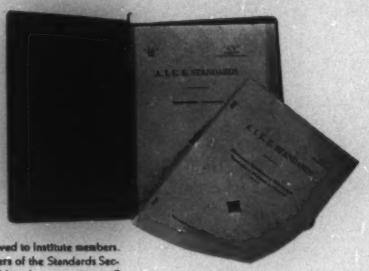
A.I.E.E. STANDARDS

THE Standards of the American Institute of Electrical Engineers now comprise forty-eight sections on electrical machinery and apparatus. They are chiefly devoted to defining terms, conditions, and limits which characterize behavior, with special reference to acceptance tests, and many of them are recognized officially as American Standards.



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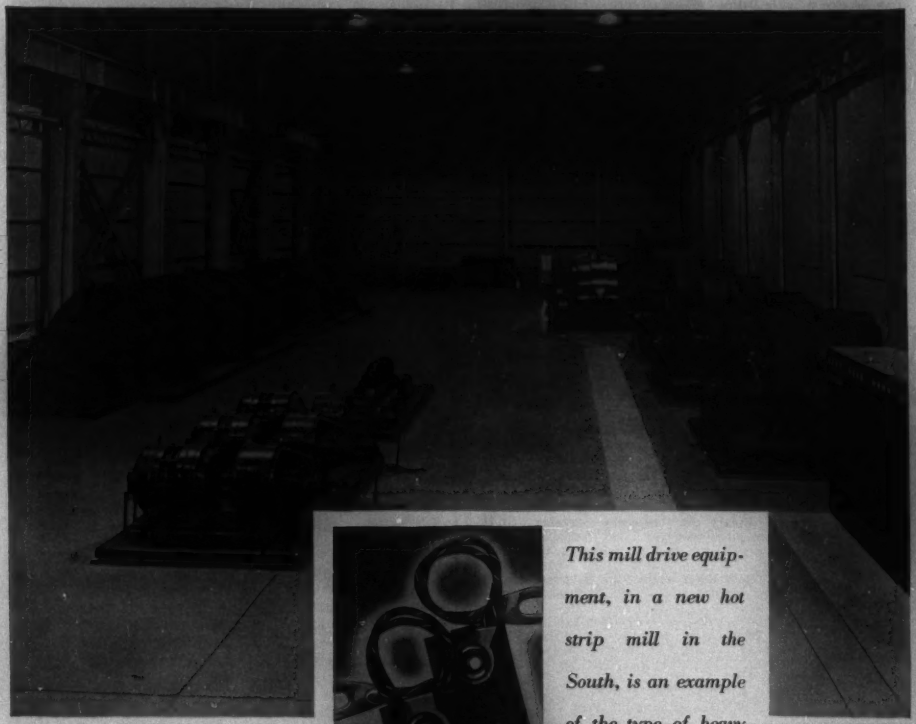

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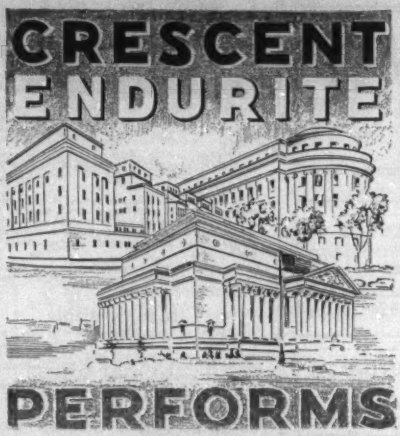

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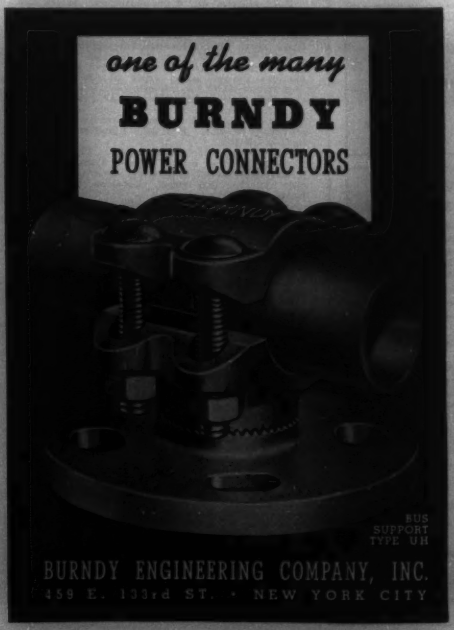

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ELEC ENGR, 15 yrs engg, contracting; 3 yrs sales; des, spec, illum, supt, appraisal, estimating, purchasing—apts, schs, institutions, indus and office bldgs; prefers consulting engg, contracting, sales, anywhere. AIEE, IES. E-436.

ASST ELEC ENGR, 31, married; 5½ yrs at NYU; 6 yrs testg, inspection and supervision. Capable des small precision mechanisms. Some draftg. Desires pos with engg future. E-438.

GRAD E.E. with 12 yrs exper in indus des, prod, purchasing and sales. Has energy and administrative ability. Now employed but wishes to make new connection with increased opportunities. E-440.

E.E., 1921, Prof license N.J., 5 yrs indus engr, estimates, reports, des, devpmt; 11 yrs des engr, central station and substation. Foreign language, German. E-443.

E.E., 32, married; 10 yrs exper: Des and field engg for control and protective relay systems; supervising maintenance automatic substations; G.E. test, service engg. Desires asst engg pos. E-444.

E.E., married, 40; 4 yrs contractor; 12 yrs city distr, transm, overhead, underground. Now supervising conversion underground radial system into network with RC secondary; also maintenance, oprn. Exper des special accessories. E-448.

EXPORT MGR, engr, 40, linguist, Am.-European exper, excellent correspondent; good connections Europe, Asia; exper all phases export-mport; available for mfr or export house desiring to build up export business. E-449.

GRAD E.E., 5 yrs overhead distr and transm; 8½ yrs factory test and inspection for purchaser, all classes of eqpt. Best ref. Location anywhere in U.S. E-450.

E.E., B.S., Univ Mich, 1937; 27, married; began Mich State Board Exams; 2 yrs with consulting engr, layout, spec, testg, reports, pwr plant, oprn checks, gen engg. Location immaterial. E-446-9007-Chicago.

E.E., M.S. in June, single, 28. B.S. 1932. Exper 5 yrs gen business, 16 mos Westinghouse generator test. Desires work as Jr Engr; constr, mfg or util co. E-447.

B.S.E.E., Duke Univ, '38; 25, single; 2 yrs com lab asst; one yr radio research. Exper radio operator, radiotel, first class license. Desires pos com engg. Location immaterial. Salary secondary. E-451.

DISTR ENGR, 25, married. 5 yrs maintenance pwr plants and distr systems, oil refinery and sulphur fields. Tau Beta Pi, Phi Kappa Phi, Reg Prof Engr. Location, U.S., East preferred. E-437.

E.E., B.S., 1934, 28; 2 yrs meter testg, one yr system load dispatching, 2 yrs electronic work, com, telemetering, remote control. Radio tel first class if necessary. Desires pos electronic applications. Employed. E-445.

PATENT ATTORNEY, 34, married; Bar member; exper in patent office, corp patent dept, patent law firm, own practice; B.S. and Law degrees. Retainer, per diem or salary. Location preferred, West. E-442.

B.S.E.E., 1935, M.S. 1937, Case; 27, single; 2 yrs grad asst mech dept. Sigma Xi, Theta Tau. Exper induction hardening and control. Desires teaching, control field. E-452.

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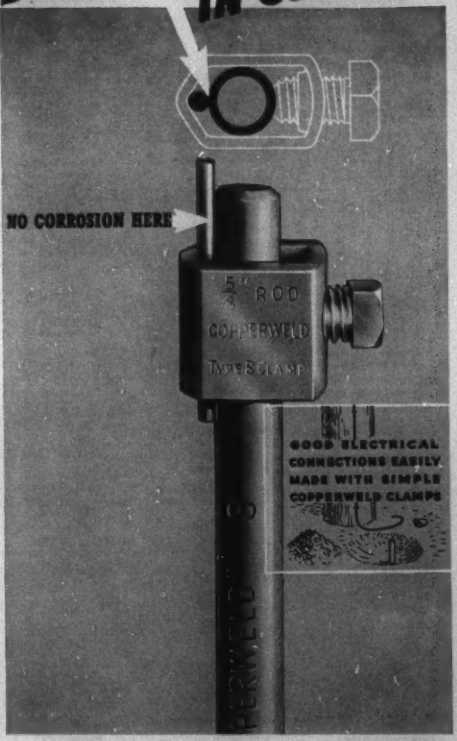

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TURBINES
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WELDERS, ARC
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WELDING WIRE
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General Electric Co., Schenectady, N. Y.
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WIRES AND CABLES

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Aluminum Co. of America, Pittsburgh

Armored Cable
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Asbestos Covered
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General Cable Corp., New York
General Electric Co., Bridgeport, Conn.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Bare Copper
American Steel & Wire Co., Chicago
Copperweld Steel Co., Glassport, Pa.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Roebling's Sons Co., John A., Trenton, N. J.

Bronze
Copperweld Steel Co., Glassport, Pa.

Copper Covered Steel
American Steel & Wire Co., Chicago
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York

Flexible Cord
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Heavy Duty Cord
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Okonite Company, The, Passaic, N. J.
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Lead Covered (Paper and Var. Cambric Ins.)
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Magnet
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.

Rubber Insulated
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton N. J.

Tree Wire
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
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Crescent Ins. Wire & Cable Co., Trenton, N. J.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
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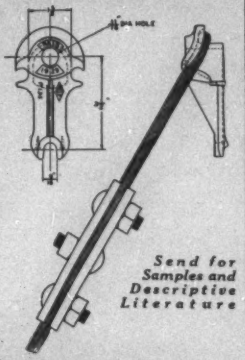

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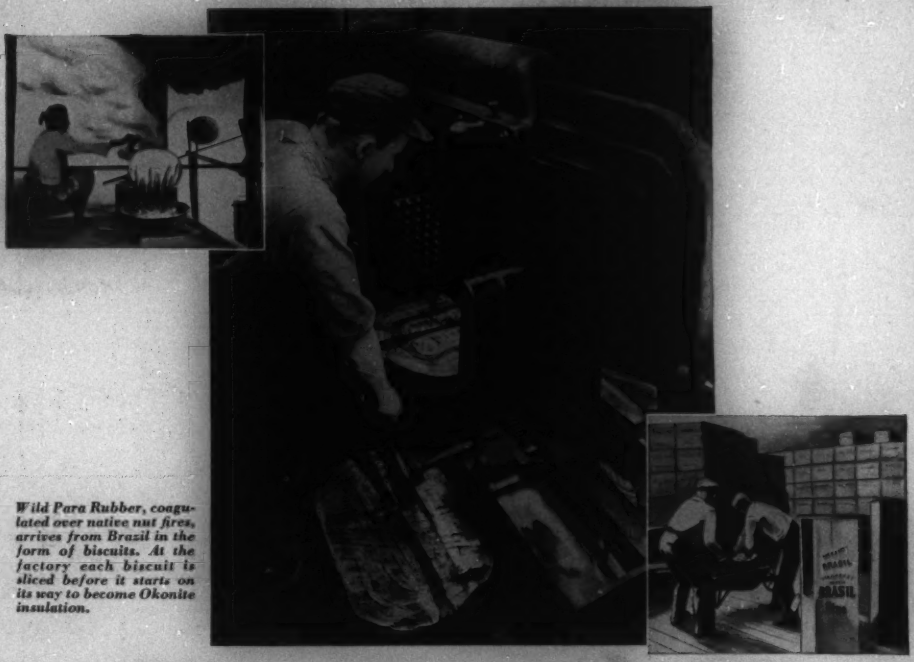

Wild Para Rubber, coagulated over native nut fires, arrives from Brazil in the form of biscuits. At the factory each biscuit is sliced before it starts on its way to become Okonite insulation.

Better Insulation is Made by Using WILD, UP-RIVER FINE PARA RUBBER

THE Okonite formula provides a dense, uniform, tough insulation containing not less than 30% by weight (over 60% by volume) of new Wild, Up-river Fine Para rubber, the *only* rubber ever used in Okonite Rubber Insulation. Okonite never contains low grade or cheaper rubbers, reclaimed rubber, rubber substitutes, or plantation rubber.

Recognized authorities state that Wild, Up-river Fine Para rubber has better aging qualities, consistent uniformity, greater original toughness and higher resistance to solvents than plantation rubber. These characteristics are undoubtedly due to the fact that the rubber is obtained from virile, sturdy trees that have survived the process of natural selection in the jungles of the Amazon.

Para rubber reaches the Okonite factory in the form of biscuits, which are sliced, ground and washed to remove all impurities and foreign matter. The thoroughly cleansed rubber is then rolled into sheets and suspended for at least 30 days in dark, drying rooms. When these operations are completed, the rubber is ready to be used in making Okonite insulation.

The exceptionally long life of Okonite rubber insulated wires and cables proves the wisdom of using Wild, Up-river Fine Para rubber.

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